

BRAIN CIRCUITS
New Clues to Mental Illness

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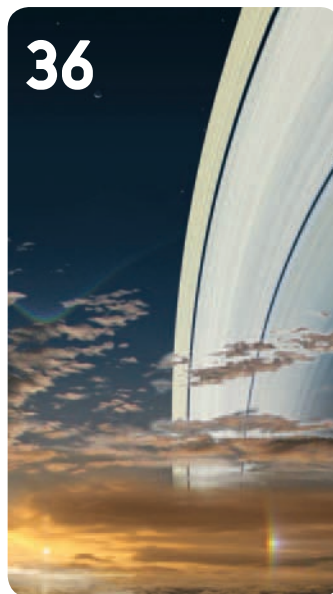
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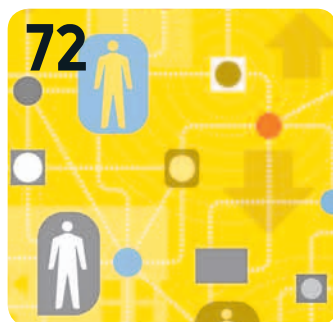
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How can we sustain life on a planet undergoing many profound changes simultaneously? Find an array of proposals in this issue. Photoillustration by Aaron Goodman.

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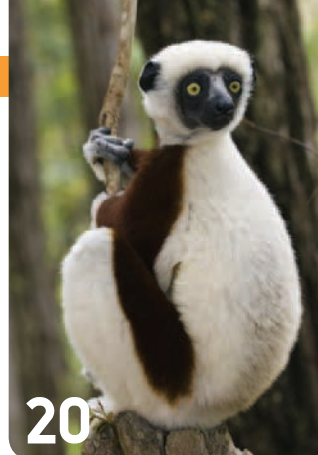
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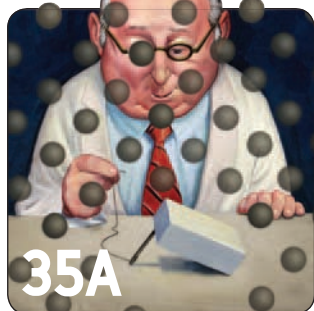
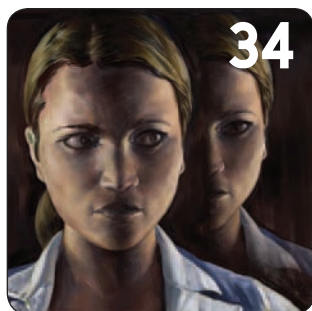
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Small World

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As I type this column, several recent storms are weighing on my mind. Winter snowfalls around the country have sparked questions about climate change yet again. Skeptics ask, How can warming be happening if we're getting big snows? As if we could determine the world's condition during a single season. In fact, one symptom of a changing climate could be more varied or more extreme weather—but a couple of heavy snows wouldn't prove that either. January was slightly warmer in the U.S. than average, in any case.

Another storm surrounds "Climategate." More than 1,000 private e-mails were stolen from the University of East Anglia's Climatic Research Unit and publicly released last November. Climate doubters have asserted that the e-mails prove that science surrounding global climate change is not settled and that the data in favor of it were misrepresented.

Disturbingly, a few mistakes were also recently uncovered in the second of the climate research reports produced in 2007 by the Intergovernmental Panel on Climate Change; the second report examines the current effects of climate change and forecasts future effects. (No errors have been found in the first, and most often quoted, report, which says that the evidence is incontrovertible that human activity is causing the atmosphere to warm and the seas to rise.)

Last, in December, the much anticipated climate summit in Copenhagen failed to produce a significant agreement to curb greenhouse emissions; at the same time, U.S. legislation on those fronts has stalled.

As we mark the 40th anniversary of Earth Day this April, what are we to make of these events? It is true that atmospheric science is complex and climate models are imperfect. Clearly, scientists, who are

only human after all, are also imperfect. But the advancement of science involves a preponderance of evidence. Thousands of studies, conducted over decades, indicate that humanity's thumbprints are molding the planet. Readers of *Scientific American* first learned that excess carbon dioxide could detrimentally affect climate in a feature article that ran back in 1959—that's right, 50 years ago. Today science is still grappling with uncertainties over the degree of human influence, but the work of thousands of researchers before and since that 1959 article shows that it does exist.

In this issue, a special report starting on page 53 reveals how we have fundamentally altered Earth—its climate, its resources, its ecosystems—and offers ideas for what we can do about it. "Boundaries for a Healthy Planet," by atmospheric scientist Jonathan Foley, explains the safe thresholds for environmental processes that profoundly affect sustainability. Then, "Solutions to Environmental Threats" provides a set of experts' takes on approaches we could employ to keep those processes within limits. Next, in "Breaking the Growth Habit," Middlebury College scholar in residence Bill McKibben contends that, to survive, society must end its addiction to economic growth in favor of smart maintenance of wealth and resources. Skeptical? Staff editor Mark Fischetti questions such assertions in "Bill McKibben, Challenged." Whether you agree with the notions or not, we hope you will find the exchange, and the special section as a whole, informative and thought-provoking. ■



MARIETTE DICHRISTINA
editor in chief

ETHAN HILL (DiChristina); NASA (Earth)

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Hydrothermal Vents ■ Ocean Policy ■ Ancient Greeks



DECEMBER 2009

■ Lost Nucleotides

Although Alexander S. Bradley's article "Expanding the Limits of Life" provides a fascinating account of the discovery of microbes in a previously unknown kind of hydrothermal vent ecosystem on the seafloor, it does not substantiate his claim that the findings hint that life may have originated in an environment like the Lost City hydrothermal vent.

Bradley suggests that Lost City produces "small organic acids such as formate and acetate" and that similar vents might have produced "simple organic acids" and "even more complex fatty acids" or "at least simple organic compounds." Such statements do not begin to address the conditions and processes that led to the assembly of the nucleotides—adenine, guanine, cytosine, thymine and uracil—nor do the statements indicate that the materials necessary to form the nucleotides might be present in hydrothermal vents.

Studies of life in hydrothermal vents and of the chemistry of hydrothermal vents have provided no information about the evolution of RNA and DNA and of their nucleotides from inorganic and simple organic molecules.

Richard A. Ely
 Dallas, Tex.

BRADLEY REPLIES: *The reader calls attention to a long-standing question in origins of life research. Scientists widely agree that RNA preceded DNA as the molecule of heredity. But it is not clear whether RNA preceded or followed the origin of metabolism,*

"We need to find the 'Ardi' of the Antikythera."

—Lowndes Whatley ROSWELL, GA.

which relies on the chemistry of much simpler organic compounds. Reconciliation of the geochemical requirements for the origins of RNA and metabolism has remained elusive—we do not yet have a theory for the origin of life. Until we do, sites like Lost City provide critical constraints on the range of potential prebiotic environments on Earth and beyond.

■ Zoned In

Having long argued that tradable rights and subleasing options are critical components of ocean zoning, I was encouraged to see these ideas displayed so prominently in "Zoning for Oceans" [Perspectives]. The ability to trade and negotiate encourages participation in what otherwise could be a very rigid top-down management approach. It can also encourage more efficient use of fish and other resources that are prone to shift over space and time, reducing the necessity during the design phase of trying to match the ecosystem scale with the policy scale—nearly impossible given the myriad socioeconomic and ecological considerations. For more details, please visit Resources for the Future (www.rff.org/oceanzoning).

James N. Sanchirico

Department of Environmental Science and Policy
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■ The Incredible Mechanism

After the marvel, shock and awe of the Antikythera mechanism described by Tony Freeth in "Decoding an Ancient Computer," there are more questions. This machine was obviously not a one-off

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or even the first of its kind; there had to be predecessors. Otherwise it would be as if someone 1,000 years from now found an Infiniti Q45 buried in mud and said we must have got tired of walking. We need to find the “Ardi” of the Antikythera.

Then there is the manufacturing. Making machine gears requires precision tools and considerable expertise. These were not Rolex watches, but they had to have a high level of precision to operate so many gears

in the drive train. Below a certain level of precision the inefficiency of the gearing would

ANTIKYTHERA mechanism revealed unexpected sophistication in ancient-world technology.

make the whole thing inoperable. To make a large, thin gear on a shaft with very small gear teeth mesh without wobbling, run in both directions, and control dials and pointers several gear sets away without much play or lash requires a level of sophistication in metallurgy, machine design and precision machining on a level with the concept, design and purpose of this incredible mechanism.

Lowndes Whatley
Roswell, Ga.

Exit Strategy

In “Portrait of a Black Hole,” Avery E. Broderick and Abraham Loeb explain that inside the event horizon of a black hole everything moves toward the singularity. In particular, any virtual gravitons emitted by the singularity will be trapped inside that singularity. Therefore, there could be no gravitation field outside the singularity, and the space around the singularity must be flat. But in that case, nothing would hinder the virtual gravitons from freely propagating. Is there a solution to this conundrum?

Moshe Rozenblit
Jersey City, N.J.

EDITOR GRAHAM P. COLLINS REPLIES: *The question reminds me of the one time in my life I spoke to Richard Feynman. I was in 7th form in high school, and after Feynman gave a public lecture at Auckland University I went up and asked him: If nothing can get out of a black hole, how could the gravitons that create its gravitational field get out? The answer is that the gravitons are virtual particles, which can move faster than the speed of light and thus can escape from the black hole.*

War or Peace

I was disappointed and dismayed by Lawrence M. Krauss’s “War Is Peace” [Critical Mass]. I agree with his political positions, but the way he presented them was shallow, unthoughtful and insulting to people who have genuinely held positions that differ from his own.

Krauss’s piece makes the magazine look like a liberal blowhard—especially because Krauss provides no thoughtful policy analysis, no new insights into the science of health care or politics, and it treats anyone with whom he disagrees with great disrespect. (“Zombielike protesters”? No—active citizens who disagree with him.)

David G. Haskell
Department of Biology
University of the South
Sewanee, Tenn.

KRAUSS REPLIES: *I appreciate the concerns expressed by Haskell, but I think he misinterpreted the point. My piece was not about health care or climate change per se. It was about disinformation replacing information in the media regarding such issues. It was in this regard that I expressed contempt for both right-wing fanatic radio hosts (if I knew of any really left-wing fanatic radio hosts I might respond equally negatively) and ex-politicians who fabricate claims about “death panels.” Thus, it is not their views that I tried to express contempt for. It is their lies and distortion. No doubt I could have been more polite, but I think it is an issue we need to be upset about.*

ERRATA In “Expanding the Limits of Life,” Alexander S. Bradley writes that “up to one third of the microbes at Lost City are methanogens belonging to the family Methanosarcinales.” That should be the order Methanosarcinales, not the family.

In “Setting Boundaries” [News Scan], David Biello wrote that one cubic kilometer was equal to “about 264 trillion gallons.” The correct conversion is 264 billion gallons.

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Lethal Dose ■ Russian Vermin ■ Fear of Meat

Compiled by Daniel C. Schlenoff

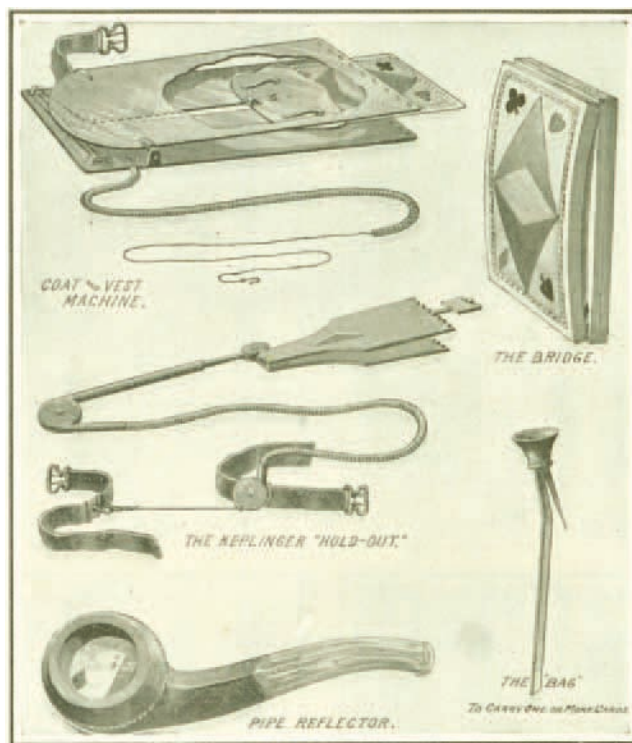
APRIL 1960

RADIATION—"With the new measurement of the mean lethal dose for reproductive function of mammalian cells, it is now possible to explain the relatively low mean lethal dose of 400 to 500 roentgens for the entire body. Such a dose leaves only about 0.5 per cent of the body's reproducing cells still able to multiply. Death, however, will not be immediate. The cells have each absorbed an almost infinitesimal amount of radiation energy. Though they have suffered an appreciable amount of chromosomal damage, their enzymatic machinery is, by and large, still active. Each such cell continues to perform its physiological functions in reasonably normal fashion until the time comes for it to reproduce. But at the next division, or at the next one or two divisions, reproduction will fail. —Theodore T. Puck"

APRIL 1910

VERMINOUS RAILROADS—"The Potsdam rail shops have been confronted with the difficult task of disinfecting the rail cars. It seems that the coaches which return from Russia are literally a-swarm with vermin. Even after the cars had been cleaned with true Teutonic thoroughness, there was still the possibility that living disease germs might lurk in the walls and hangings. The problem seems to have been successfully solved. The disinfecting apparatus consists of an iron cylinder, of a length of about 72 feet. Even during the coldest weather the cylinder can be raised to 140 degrees F by steam pipes. After which the air is pumped out of the cylinder. All moisture is evaporated from the car without injuring the parts by excessive heat."

CARD CHEATS—"Games of chance have a fascination for all classes of individuals, and the professional 'sharp' has made this weakness a means for earning an easy livelihood. Cards are the most fertile field for the gambler's revenue. Various devices have been employed called 'hold-outs,' mechanical contrivances concealed in the sleeve or vest which by a very slight pressure or movement in one direction, will instantly shoot out a card into the gambler's hand and recede again into the sleeve. One of the most ingenious and perfect of these was invented by a gambler named Keplinger ('the Lucky Dutchman'), and has ever since



GAMBLER'S ARSENAL: Ingenious tools for card sharps, 1910

been known as the Keplinger 'hold-out.' The apparatus was worked by the knees, so that no motion of the arms or body was necessary. A simpler device is the 'bag,' stuck into the wood of the underside of the table. Cards can be inserted into the clip thus formed.—Hereward Carrington"

APRIL 1860

ELECTRIC THEORY—"The results of the experiments instituted by Sir William Grove are exceedingly curious, and must be regarded as all but proving the truth of the modern theory, which assumes that electricity is not, in any sense, a material substance but only an affection (state) or motion of the particles of ordinary matter. If electricity is unable to pass over or through a vacuum, it is probable that all the other so-called imponderable forces—light, heat, magnetism, and possibly attraction—obey the same law, and as these agencies freely travel the interplanetary spaces, the supposition of Newton that such spaces may be filled with an ethereal form of matter receives an indirect but powerful support."

EPIZOOTIC—"The terrible epidemic of cattle disease, by its continuous spreading, threatens to become one of the greatest scourges that has ever visited the country. The imagination is appalled at the contemplation of the thousands of herds from Maine to Texas being visited by this wasting and fatal malady. The dread of its loss among the agricultural community, and the fear of diseased meat in all our cities, may be partly conceived but cannot be fully realized. In Massachusetts three commissioners are to be appointed to investigate the subject. Authority has been given them to have slaughtered, at the

expense of the state, all the cattle that are sick or that have been exposed to the contagion. It is purely a disease of the lungs, affecting the animal in no other organ."

[NOTE: The disease was probably contagious bovine pleuropneumonia.]

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Technology

Internet Ideology War

Google's spat with China could reshape traditional online freedoms **BY MICHAEL MOYER**

LATE LAST YEAR A SERIES OF SOPHISTICATED INTERNET ATTACKS emanating from China burrowed deep into the computer systems of some two dozen U.S. corporations, among them Northrop Grumman, Dow Chemical and Yahoo. One fought back. After revealing that the attacks targeted not only its core intellectual property but the e-mail accounts of Chinese human-rights activists, Google announced that it would stop censoring search results on Google.cn, its Chinese-language search engine. The move led to threats by the Chinese authorities to shut down Google's operations inside China.

The charges and retaliations seem reminiscent of so much cold war bluster, and indeed this encounter could be the first great clash of the 21st century's two emergent superpowers—Google and China. More than a battle over territory or market share, it is a conflict over ideology, one that pits a free and open Internet that empowers individuals at the expense of existing power structures against an Internet micromanaged by those powers. “What we're talking about here is a defense of the essence of the Internet,” says Jeff Jarvis, director of the interactive journalism program at the City University of New York and author of *What Would Google Do?* (HarperCollins, 2009).

More than any other organization, Jarvis says, Google has both the means and the incentive to ensure that the Internet remains open. It is also one of the few organizations with a broad enough online presence to define the standard operating rules of the Internet, explains Rebecca MacKinnon, a researcher at the Center for Information Technology Policy at Princeton University. Google is “the first mover in so many different sectors,” she says. “It can set the norms for how open one can be online.”

For anticensorship advocates, Google is also one of the few organizations with enough raw computing power to significantly aid the fight against authoritarian regimes. “My hope, and expectation, is that Google engineers who might have been a bit halfhearted about implementing censorship mandates in Google.cn could be full throttle in coming up with ways for Google to be viewed despite any network interruptions between site and user,” says Jonathan Zittrain, a co-founder of the Berkman Center for Internet and Society at Harvard University.

Google could combat China's censorship efforts by helping those within China breach the so-called Great Firewall. As with buildings in the physical world, every location on the Internet has an address associated with it—an Internet protocol, or IP, address. In addition to filtering certain keywords, the administrators of the Great Firewall maintain a huge list of blocked IP addresses. Circumvention tools send a user to an unblocked address, then pipe in all outside information through that “proxy”



WALL OF SILENCE: The Chinese government requires Internet firms to hide objectionable content from users, including those here in the city of Guilin. Google is the first major company to refuse to comply.

IP address. Yet at any time, this tunnel could collapse. “One of these IP addresses could last forever, or for months, or for minutes” before the authorities find it and block it, says Hal Roberts, an expert in circumvention tools at the Berkman Center.

Hence, any large-scale circumvention effort requires a huge number of addresses to cycle through, along with an enormous amount of bandwidth to support all the tunneling. “If we could magically convince all Chinese people to use [these services],” Roberts says, “then someone would have to pay for the entire outgoing bandwidth of China.” That might strain Google's resources, but not by much.

Still, there are good reasons for Google not to start this kind of proxy war. Promoting a free and open Internet is one thing; actively undermining the laws of a sovereign nation is another. Moreover, these same circumvention tools also work as anonymity tools—anyone can use proxy servers to hide their true identity. “This makes them very useful for all kinds of bad activities,” Roberts says. “They could be used to hack Google's servers or for attacks against Google services using click fraud and spam. So there's a strong question from Google's point of view whether it is in their best interest to promote them.”

No matter what course the standoff takes in the months and years to come, it has brought into focus this battle for control

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over how unrestricted the Internet should be. Right now users depend on companies such as Google to defend the Internet from forces—governmental and otherwise—that would exert more top-down control over it. That may not be enough. “Google—along with a whole range of Internet companies and communications companies—has created this layer on which we depend,”

MacKinnon observes. Yet there is no set of rules, no Internet Bill of Rights, that would codify the rights of citizens online. “These companies are saying, ‘We’re good people, trust us,’” MacKinnon says. “As with a benevolent dictatorship, it works really well when the current leader is a great guy. But then he dies, and his evil son takes over. And then everybody’s screwed.”

Unfree Spirit: NASA’s Mars Rover Appears Stuck for Good

The Mars rover Spirit, which in January passed its sixth anniversary of landing on the Red Planet, will apparently rove no more. NASA announced in a January 26 teleconference that Spirit, stuck for months in a patch of soft soil known as Troy, has been designated a “stationary research platform.”

Doug McCuistion, director of NASA’s Mars Exploration Program, called the rover’s plight “a golfer’s worst nightmare—the sand trap that no matter how many strokes you take, you can’t get out of it.”

Spirit lost the use of one of its six wheels four years ago, and another wheel gave out during the rover’s recent struggles at Troy. With only four functioning wheels, the extrication process has been hindered, said John Callas, project manager for Spirit and its twin rover, Opportunity, at the NASA Jet Propulsion Laboratory in Pasadena, Calif. (Opportunity soldiers gamely on from its landing site halfway around the planet.)

The most immediate challenge for Spirit will now be surviving the long, frigid Martian winter, for which the rover is not well positioned to maximize its gathering of solar power. And without the energy necessary to keep its components warm, Spirit could experience a fatal electronics failure. Callas estimated that temperatures could fall below -40 degrees Celsius, which would approach the boundaries of the rover’s operating specs.

Cornell University’s Steve Squyres, the principal science investigator for the rovers, expressed hope “that Spirit will survive this cold, dark winter that we have ahead of us.” If it can hang on, Squyres said, spring will bring a slew of opportunities for Spirit to conduct scientific investigations on Mars.

—John Matson

WHEELS DOWN: In better times, such as this sampling done in 2004, Spirit explored different areas of Mars.



Research & Discovery

Problem Solved, LOL

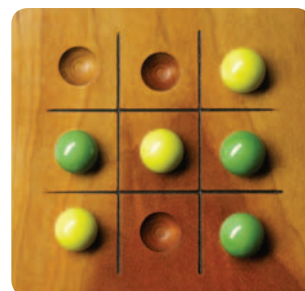
Blog comments point to a new, faster approach in math

BY DAVIDE CASTELVECCHI

IN THE MID-20TH CENTURY THE ENCYCLOPEDIC WORKS OF FRENCH mathematician Nicolas Bourbaki traced every mathematical concept back to the subject’s foundations in the theory of sets—the stuff of Venn diagrams—and changed the face of his field. Like many of his notions, Bourbaki existed only in the abstract: he was the pseudonym for a tight-knit group of young Parisian researchers. The Internet-age version could be D.H.J. Polymath, another collective pseudonym who could define a new style of mathematics.

Polymath began life on the blog of Timothy Gowers, a University of Cambridge winner of the Fields Medal, mathematics’ most coveted prize. In a blog post in January 2009, Gowers asked whether spontaneous online collaborations could crack hard mathematical problems—and if they could do so in the open, laying the creative process out for the world to see. Web-based scientific collaborations and even “crowdsourcing” are now common, but this one would be different. In typical online collaborations, scientists each perform a small amount of research that contributes to a larger project, Gowers pointed out. In some cases, citizen-scientists such as bird-watchers or amateur astronomers collectively can make significant contributions. “What about the solving of a problem that does not naturally split up into a vast number of subtasks?” he asked. Could such a problem be solved by the readers of his blog—simply by posting comments?

For a first experiment, Gowers chose the so-called density Hales-Jewett theorem. This problem, Gowers says, is akin to “playing a sort of solitaire tic-tac-toe and trying to lose.” The theorem states that if your tic-tac-toe board is multidimensional and has sufficiently many dimensions, after a short while it is impossible to avoid arranging X’s into a line—you cannot avoid winning no matter how hard you try. Mathematicians have known since 1991 that the theorem was true, but the existing proof used sophisticated tools from other branches of math. Gowers challenged his blog’s readers to help him find a more elementary proof, a problem generally considered quite hard.



YOU WIN: Online collaboration solved a problem akin to playing solitaire tic-tac-toe and trying to lose.

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The project took off a lot faster than Gowers expected. Within six weeks, he announced a solution. Turning the proof into a conventional paper took longer, especially because the argument was scattered across hundreds of comments. But last October the group posted a paper on the online repository arxiv.org under the name of D.H.J. Polymath, where the initials are a reference to the problem itself.

In another way, however, the project was a bit of a disappointment. Just six people—all professional mathematicians and “usual suspects” in the field—did most of the work. Among them was another Fields medalist and prolific blogger, Terence Tao of the University of California, Los Angeles.

Pooling talent has its advantages, Gowers says. When trying to solve a problem, mathematicians usually make many failed attempts, in which they try lines of reasoning that can turn out to be “blind alleys,” after weeks or months of work. Often those lines of reasoning that seem promising to one expert look obviously fruitless to another. So when every attempt is exposed to public feedback, the process can become much faster.

Tao describes the experience as “chaotic” but a lot of fun and “more addictive than traditional research.” Gowers has since kicked off a few more online collaboration projects, and so has Tao—and nonprofessionals have begun to contribute in ways that are “genuinely useful,” Gowers says. These high-brow amateurs included a teacher, a priest and a math Ph.D. who now works in computing. But how widely the approach will be adopted is unclear. A number of hard problems may be suitable, Tao says, such as devising an algorithm for playing chess that is not based on the brute-force calculation of possible future moves. Famous mathematical conjectures may not be as amenable, because those problems tend to have a long history—and experts already know all the blind alleys.

Rafael Núñez, a cognitive scientist at the University of California, San Diego, who has studied the mental and social process of doing mathematics, points out that problem solving is just another human activity. When mathematicians work together in front of a blackboard, they communicate in subtle ways with their voice and body language, clues that will be lost in online collaborations. But mathematicians will adjust to the new medium, just like people have adjusted to doing all kinds of other things in a connected world, Núñez notes: “Anything we do online is different, not just mathematics.”

In the end, the open nature of the project may have been its most important feature. As Gowers wrote on his blog, Polymath may be “the first fully documented account of how a serious [math] research problem was solved, complete with false starts, dead ends, etcetera.” Or, as Tao puts it, the project was valuable because it showed “an example of how the sausage is made.”

Humans Might Have Faced Extinction

Early humans living about one million years ago were extremely close to extinction. Evidence from a novel genetic approach, one that probes ancient DNA regions, suggests that the population of early human species back then, including *Homo erectus*, *H. ergaster* and archaic *H. sapiens*, was 55,500 individuals, tops.

Lynn Jorde, a human geneticist at the University of Utah, and his colleagues came to this conclusion after scanning two completely sequenced modern human genomes for a type of mobile element called Alu sequences, which are short snippets of DNA that move between regions of the genome. They shift with such low frequency that their presence in a region suggests that it is quite ancient. Because older Alu-containing portions have had time to accumulate more mutations, the team could also estimate the age of a region.



HUMAN FAMILY over time includes (left to right) *Homo heidelbergensis*, *erectus* and *neanderthalensis* (top row) and *erectus* and an archaic *sapiens* (middle). Bottom row shows three modern *sapiens*.

The scientists then compared the sequences in these old regions with the overall diversity in the two genomes to come up with an ancient census figure of 55,500. (Population geneticists actually calculate the so-called effective population size, which is an indicator of genetic diversity and is generally much lower than absolute population numbers; in this case, the effective population of humanity 1.2 million years ago was 18,500, which Jorde used to estimate the total population number.) The findings appear online in the January 19 *Proceedings of the National Academy of Sciences USA*.

The small number is surprising because, according to the fossil record, members of our *Homo* genus were spreading across Africa, Asia and Europe, suggesting that the hominin numbers should be expanding, Jorde says. A major setback must have occurred back then, he thinks, as devastating as a purported supervolcano thought to have nearly annihilated humans 70,000 years ago. “We’ve gone through these cycles where we’ve had large population size but also where our population has been very, very small,” he observes.

—Carina Storrs

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Swept Away

New modeling buoys raft theory for origin of Madagascar's mammals **BY KATE WONG**

THE AFRICAN ISLAND OF MADAGASCAR, SITUATED SOME 430 kilometers off the coast of Mozambique, is famous for its unique fauna, particularly its charismatic primates, the lemurs. But how the lemurs and other land mammals got there has proved an enduring mystery. To that end, new evidence supports a theory that some experts once considered unlikely: namely, that the forerunners of Madagascar's modern mammals reached the island millions of years ago by drifting from the African mainland across the Mozambique Channel on giant rafts of vegetation ripped from the shore and launched out to sea by violent storms.

Reconstructing ancient dispersal routes is a complex exercise. On Madagascar this puzzle is complicated by the fact that the fossil record of mammals from the past 65 million years is meager. Based on the paltry available clues, some researchers thought the ancestral mammalian stock arrived via a landbridge that later disappeared with the shifting of landmasses. But geologic evidence of such landbridges is weak at best. Moreover, this theory cannot account for why the island's many endemic terrestrial mammal species represent only four of Africa's broader mammal groups called orders. And all of Madagascar's land mammals are relatively small—no elephants, lions or giraffes there. If landbridges existed, critics argued, why did only small mammals belonging to these four orders make the trip over?

To account for the shortcomings of the landbridge explanation, paleontologist George Gaylord Simpson proposed the rafting theory in 1940. In the decades that followed, his idea gained credence from studies by molecular biologists, who compared DNA sequences of Madagascar's modern land mammals and concluded that the founding populations of the four orders colonized the island independently at different times between 60 million and 20 million years ago—exactly the sort of sporadic pattern one would expect if the migrants washed ashore in rare rafting events.

Still, Simpson's scenario seemed to have a few leaks. Chief among them was the received wisdom that the ancient currents, presumed to be similar to modern conditions, flowed away from Madagascar, not toward it. If so, then castaways would have

drifted back to the mainland or to the north or south, never east toward Madagascar.

But the new work, detailed in the February 4 *Nature*, indicates that, in fact, prehistoric currents were not the same as they are today (*Scientific American* is part of Nature Publishing Group). Jason R. Ali of the University of Hong Kong and Matthew Huber of Purdue University used paleogeographic reconstructions and paleo-oceanographic modeling to determine that some 60 million years ago, the African continent and Madagascar both sat about 1,650 kilometers south of their modern-day positions, placing them in a different ocean current system. Back then the surface currents would have flowed from Mozambique and Tanzania east toward Madagascar. During peak periods, their eastward flow could have enabled accidental rafters to reach Madagascar from the mainland in as little as 25 to 30 days.

"The success rate of conveyance across the Mozambique Channel was likely extremely low, with many rafts not making it across and, consequently, the animals on them perishing at sea," observes David W. Krause of Stony Brook University, who wrote a commentary accompanying the report. "But remember that there were millions of years and many more millions of storms involved." Furthermore, some animals, including lemurs,

can enter into hibernation or another energy-conserving state known as torpor, which could have aided survival on the open ocean.

Ali and Huber's study "is an excellent piece of work demonstrating probable rafting," comments Elwyn Simons of Duke University. He adds that many groups of mammals that live on the mainland today were not present during the early phases of colonization of Madagascar, limiting potential migrant diversity.

Whether the newly modeled conditions prevailed long enough to account for all four of the migration events molecular biologists have detected is uncertain, although preliminary data suggest that Madagascar did not move into its present location until some 15 million years ago—well after the last proposed dispersal event. More simulations of ocean currents from different time periods would bolster their case—and hang the landbridge theory out to dry.



LEMURS such as this Verreaux's sifaka are among Madagascar's unique mammal species.

Biofuel from Bacteria

E. coli turned into cellulose-chomping biodiesel refineries **BY DAVID BIELLO**

THE BACTERIUM THAT CAUSES THE MOST CASES OF FOOD POISONING in the U.S. could someday be responsible for much of the country's transportation fuel. Researchers have used the tools of synthetic biology to manipulate the genes of *Escherichia coli*, a common gut bacterium, so that it can chew up vegetation to produce diesel and other hydrocarbons.

E. coli is popular in genetic engineering because it is deeply studied and quite hardy, able to tolerate genetic changes well, says chemical engineer Jay Keasling of the University of California, Berkeley. Researchers have already modified *E. coli* to make medicines and chemicals, and now Keasling and his colleagues have turned the organisms into biodiesel factories.

The scientists first genetically modified *E. coli* to consume sugar and secrete engine-grade biodiesel, which can float to the top of a fermentation vat—no need for distilling, purifying or breaking cells open to get the oil out, as is the case for making biodiesel from algae.

To minimize any impacts on food supplies, the investigators

then sought out genes from other bacterial species that can break down cellulose, the tough material that makes up the bulk of plants but is not fit for human consumption. The team added those enzyme genes plus an extra bit of genetic code that instructs the altered *E. coli* cells to secrete the enzyme. The enzyme then breaks down plant cellulose and thereby turns it into sugar that the altered *E. coli* can consume to make diesel.

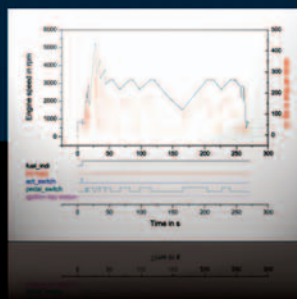
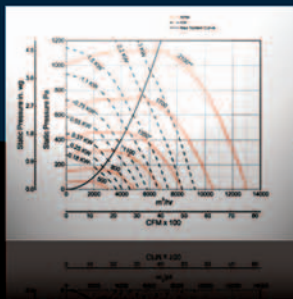
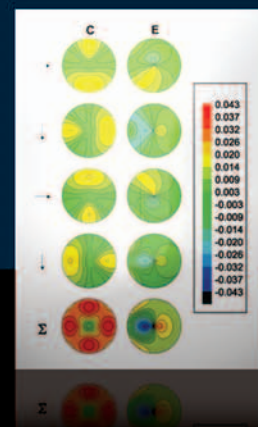
The process, described in the January 28 *Nature* (*Scientific American* is part of Nature Publishing Group), is perfect for creating hydrocarbons with at least 12 carbon atoms in them—besides diesel, the group includes jet fuel (kerosene). But it cannot yet make shorter-chain hydrocarbons such as gasoline, a deficiency Keasling is working on. After all, the U.S. alone burns some 530 billion liters of gasoline a year, compared with around 170 billion liters of diesel (and just 7.5 billion liters of biodiesel).

Keasling is not alone in his regard for *E. coli* as a fuel maker; several companies are pursuing commercial production from the hardy microbe. It "grows fast, three times faster than yeast," ex-

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plains geneticist and technology developer George Church of Harvard Medical School, and “100 times faster than most agricultural microbes.”

Still, Keasling’s *E. coli* needs more work to boost its efficiency in making fuel.



BUG JUICE: *E. coli* can be genetically modified to break down plant cellulose into sugar, which the bacteria can then convert into engine-ready biodiesel fuel.

“We are at about 10 percent of the theoretical maximum yield from sugar,” Keasling notes. “We would like to be at 80 to 90 percent to make this commercially viable. Furthermore, we would need a large-scale production process.” In creating a

novel organism, they will also remove key metabolic pathways so that it could never survive in the wild.

The challenges are not trivial, but the promise is great. Keasling has estimated that in the past such engineered microbes would need to chew up only 40.5 million hectares—roughly one quarter of the current amount of land devoted to raising crops in the U.S.—of a common tall Asian grass to produce enough fuel to meet all of the U.S.’s transportation needs.

PHOTO RESEARCHERS, INC.

Higher Watermarks

Ice-age sea-level rise brings up questions about glacier melting BY DAVID BIELLO

MALLORCA, SPAIN’S LARGEST ISLAND, IS not just a desirable place for a Mediterranean vacation; it is also a treasure trove of data on the earth’s past. Thanks to the island’s long-term geologic stability, the caves record sea levels over the past tens to hundreds of thousands of years in the form of stone structures. In examining such rock formations, a team of geologists conclude that, compared with today, sea levels were roughly one meter higher 81,000 years ago, when the world was thought to be experiencing an ice age that should have locked up water in glacial ice, which should have lowered sea level as much as 30 meters.

More disturbing, the record suggests that sea level can go up or down as quickly as two meters a century—nearly 12 times faster than sea-level rise in the past 100 years—an indication of the potential for a meter of sea-level increase within one human lifetime. “This has major implications for future concerns with sea-level

change,” says geoscientist Jeffrey Dorale of the University of Iowa, one of the authors of the new research published in the February 12 *Science*. “Our study indicates rapid rates of ice melting and ice formation. The mechanisms underlying these dramatic changes need further consideration as we look to a future of impending climate changes.”

The researchers drew their conclusions after collecting rock samples from five different caves from stalagmitelike formations known as speleothems. These structures are scattered above and below present-day sea level and thereby build up a carbonate crust left on them by the lapping waters of the sea over time. The decay of radioactive uranium and thorium in the encrusted speleothems served to date the layers.

Speleothems provide a more precise measure of historic sea level than those left in coral reefs or ancient shorelines, which had been used in the past to esti-

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PAST SEA LEVELS are indicated by yellowish bands of carbonate deposits on formations in sea caves on the Spanish island of Mallorca. Stalactites can also be encrusted with minerals left behind by seawater (*inset*).

mate primordial sea levels. In fact, the speleothem data back findings from Caribbean islands as well as the U.S. East and West coasts that sea level 81,000 years ago was at least as high as it is today and probably higher.

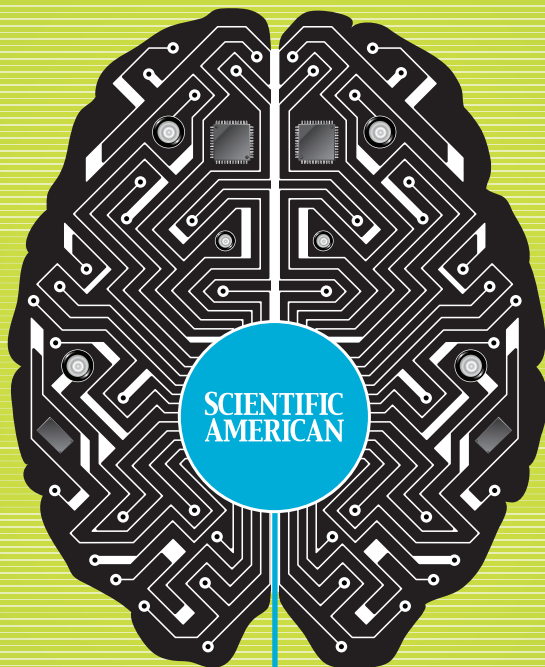
What might have caused the sea-level climb remains unclear, although the rise coincides with an increase in the amount of sunlight hitting the Northern Hemisphere resulting from slight variations in the earth's orbit, known as Milankovitch cycles. "Maybe unstable ice was involved in some of the rapid rise," Dorale speculates. "But we don't even know for sure what the ice configuration was at this time." Yet the record in rock also suggests that Milankovitch cycles cannot entirely explain ice growth or melt during the past 100,000 years, notes geologist Bogdan P. Onac of the University of South Florida, who collaborated in the analysis. "It must have been a dramatic melting event. What exactly caused it is hard to tackle with just this set of data."



Glaciologist Richard Alley of Pennsylvania State University, who was not involved in the project, calls the findings solid and careful and notes that this study confirms that ice-sheet changes can happen quickly. "It points to rather rapid shrinkage and growth of ice," he says, while cautioning that more research is needed to confirm the results. "The growth rates are surprising, but not impossible," he observes.

One thing is certain, however: the finding points to how complex the earth's climate is. "Greenhouse gases are clearly important to climate," Dorale says, "but just as clearly they are not the only major factor at work."

COURTESY OF BOGDAN P. ONAC, University of South Florida (stalactites); TONY MERINO (cave)



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Medicine & Health

Static over Statins

Should young people without cholesterol problems take statins? BY MELINDA WENNER MOYER

AN ESTIMATED 20 MILLION AMERICANS TAKE STATINS, MAKING these cholesterol-lowering drugs the most widely prescribed class in the world. In coming years, these numbers are only expected to increase. In June 2011 the full patent for Pfizer's blockbuster Lipitor (atorvastatin) will expire, making the drug significantly more affordable. And later this year the National Cholesterol Education Program (NCEP) of the National Heart, Lung, and Blood Institute will release guidelines that could recommend statins for younger people who have no cholesterol issues—a move that could stave off cardiovascular disease later in life but also introduces questions about aggressively treating the healthy.

The current NCEP guidelines, published in 2001 and revised in 2004, recommend statins for heart disease patients with LDL ("bad") cholesterol levels greater than 70 milligrams per deciliter of blood and for people who have a moderately elevated risk of heart disease as well as LDL levels above 100 mg/dL. An expected NCEP move to lower the treatment bar this year would follow a Food and Drug Administration advisory panel's vote in December 2009 to broaden the prescription base of AstraZeneca's drug Crestor (rosuvastatin) to an additional 6.5 million lower-risk Americans. The FDA usually accepts the panel's recommendations.

For many doctors, these treatment changes are overdue. With the current guidelines and prescription numbers, "you're going to miss a lot of the people who were destined to have heart attacks," says Antonio M. Gotto, Jr., dean of Weill Cornell Medical College. Joseph L. Witztum, an endocrinologist at the University of California, San Diego, argues that people should be treated with statins early in life to achieve and maintain LDL cholesterol levels below 50 mg/dL. "If you start at age 30, when you can prevent even the earliest [cardiovascular] lesions, the lifetime benefits will be really quite astonishing," he remarks. For instance, people who have low cholesterol their entire lives—such

as those born with a mutation in a gene called *PCSK9*—suffer far fewer heart attacks than people who lower their cholesterol only later in life.

Direct evidence for the benefits of statins as primary prevention—that is, for preventing heart attacks in people who do not yet have heart disease—comes largely from one clinical trial published in 2008 in the *New England Journal of Medicine*. The trial, called JUPITER and funded by AstraZeneca, enrolled nearly 18,000 subjects without heart disease who had LDL cholesterol levels below 130 mg/dL and elevated levels of the inflammatory marker C-reactive protein. The trial found that rosuvastatin reduced the risk of cardiovascular events by 44 percent as compared with placebo.

Some physicians, however, have doubts as to whether the results extend to the general population, noting that JUPITER's subjects weren't healthy at all. More than a quarter were obese, 41 percent had metabolic syndrome and about 16 percent smoked. "They've never had a [cardiovascular] event, but that

doesn't mean they're low risk—it just means they've dodged a lot of bullets," says James Liao, director of vascular medicine research at Harvard Medical School's Brigham and Women's Hospital. Although JUPITER describes its subjects as "apparently healthy," it would be more accurate to consider them at moderate risk of heart disease, notes Richard Karas, a cardiologist at Tufts University. "As with every clinical study, you shouldn't generalize the finding to people who weren't eligible for the study," he says.

Statins can also have side effects, the most common being muscle and joint pain. "Most clinicians will tell you that they see them in at least 5 percent of patients and as many as 20 percent," says Matthew F. Muldoon, an internist and clinical pharmacologist at the University of Pittsburgh Medical Center. Although the pain is typically mild, symptoms "frequently lead to com-



BAD FLOW: Carotid artery of a stroke patient had narrowed vessels caused by atherosclerosis. The condition typically results from high cholesterol, which statins can lower.

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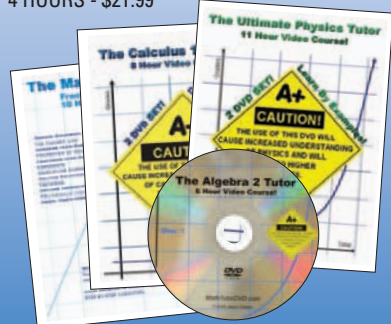
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NEWS SCAN

plaints to the doctor and changes in medication," he says. A much smaller percentage of patients suffer from severe muscle complications, like rhabdomyolysis.

But even rare side effects can be important when drugs are aggressively used. In 2007 Karas published a study in the *Journal of the American College of Cardiology* suggesting that the risk of complications increases with statin dose. If more people start taking statins and at higher doses, many more people will experience problems. "It's one thing to treat a person who's had a heart attack with a statin drug for five or 10 years, because their likelihood of a vascular event is very high. It's another thing to take 35-year-olds who

have high cholesterol and treat them for 30 years," Muldoon says. "That's a whole different argument to make and justify."

Karas points out that he is not against broader statin treatment. He simply believes that guidelines should reflect existing data. And even if the results of JUPITER do not apply to truly healthy people, that does not mean they are not relevant. "There's a sizable proportion of the American adult population that has a risk factor profile that's similar to JUPITER," Karas says. "If you look out across the U.S., it's not a very healthy population."

Melinda Wenner Moyer is a freelance science writer based in New York City.

Making Scents of Sounds

Noises may alter our sense of smell **BY LYNNE PEEPLES**

FLAVOR JUST GOT SOME COMPETITION. SMELL AND TASTE ARE KNOWN TO CONVERGE to produce the best and worst of culinary experiences, but new research suggests that information received through the nose can also be altered by noise. If confirmed, this newfound union could have potent olfactory and gustatory implications.

The discovery of a possible smell-sound sense, or "smound," came to Daniel Wesson by accident. "I was simply trying to find the way the olfactory tubercle responds to odors," he says, referring to a structure at the base of the brain that was implicated in odor detection only in 2004. But when he set down his coffee mug on a laboratory bench one afternoon, he noticed that the activity in the tubercle of the mice he was studying spiked. He picked his mug back up. Sip. Clunk. Spike.

Wesson and his colleague Donald Wilson, both at the Nathan S. Kline Institute for Psychiatric Research in Orangeburg, N.Y., decided to investigate the smound spikes more rigorously. As they describe in the February 24 *Journal of Neuroscience*, they first verified that the tubercle does indeed respond to smell. They found that 65 percent of tubercle cells from 23 anesthetized mice were activated by at least one of five odors—an important finding in its own, because no one knew if tubercle cells could discriminate odors, a process thought to be exclusive to the part of the brain known as the piriform cortex. Next, Wesson and Wilson repeated the experiment, this time presenting a subset of the cells with only a tone: 19 percent fired.

The next set of recordings "really changes the way we think

"SMOUND" PROPOSITION: What you hear may affect what you smell.



PETER SHERRARD/Getty Images

about smell,” Wesson says. He and Wilson repeatedly sent a mix of both odors and tones into tubercle cells and saw that responses from 29 percent became either enhanced or suppressed depending on the presence or absence of the second stimulus. One cell, for example, appeared not to care for either smell or sound but responded robustly to the combination.

Historical hints of perceptual interplay between smells and sounds have been reported—in the mid-1800s French perfumier G. W. Septimus Piesse catalogued odors based on analogous auditory pitches. Wesson and Wilson, though, may have found the first neural evidence. But because sensory activity does not always equate with perceived changes, they must devise an experiment to determine what their mice actually smell and hear. The perceptual shift could be significant: changes in sensory activity even smaller than what was seen in these experiments can greatly influence the senses. “In theory, one spike could allow for the discrimination between a tangerine and a mango,” Wesson notes.

Olfactory-auditory integration adds to a growing list of intimate connections be-

tween sensory systems. “While we like to think that there are five separate senses, that’s not the way it works,” remarks Donald Katz, a neurobiologist at Brandeis University. “What your brain really does is take objects and process them.”

The existence of a smound sense has broad implications. It may help elucidate the defective processing behind mysterious disorders such as synesthesia, in which patients taste colors and see flavors. And Wesson and Wilson plan to develop technology related to their findings; for instance, they hope to patent a device that emits a tone into the ear of a dog every time it sniffs, enhancing its sensitivity to, say, explosives. The necessary details will come after they identify which frequencies and intensities best amplify and suppress odors.

Of course, diners can experiment on themselves. They could see if food smells—and hence, tastes—differently based on the background sounds. You might find that your saffron risotto pairs better with Beyoncé than with Beethoven.

Lynne Peeples is a freelance science writer based in New York City.

Carcinogens Detected from “Thirdhand Smoke”

Anyone walking into a smoker’s abode can tell you that the traces of tobacco use don’t vanish when a cigarette is extinguished. Does this so-called thirdhand smoke pose a health hazard? Researchers at Lawrence Berkeley National Laboratory found that remnants of cigarette smoke don’t just inertly settle onto surfaces. Instead the left-over nicotine can react with nitrous acid vapor, an environmentally common chemical emitted from gas appliances and vehicles, among other sources. The reaction produces carcinogenic compounds known as tobacco-specific nitrosamines (TSNAs).

Secondhand smoke itself contains TSNAs, but the presence of nitrous acid in



an environment can increase their numbers by several times in the hours after smoking has ceased. And because nicotine can linger on surfaces for weeks or months, this

form of exposure might be even more persistent than firsthand or secondhand smoke, with the TSNAs being inhaled, ingested and dermally absorbed into the body. Children are likely to be the population most vulnerable to thirdhand smoke, just as they are for the secondhand variety. The findings, published online February 8 by the *Proceedings of the National Academy of Sciences USA*, are preliminary, and more research remains to be done to determine if thirdhand smoke has definite human health implications. —*Katherine Harmon*

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Chemical Controls

Congress needs to give federal agencies greater authority to test and regulate chemicals

BY THE EDITORS

This January the Food and Drug Administration warned parents not to pour hot liquids into plastic baby bottles and also to discard bottles that get scratched. Otherwise, a potentially harmful chemical might leach out of the plastic. This warning was the agency's first, tentative acknowledgment of an emerging scientific consensus: many widely used chemicals once deemed safe may not be.

But a warning was all the FDA could offer worried consumers. The agency does not have the power to force baby-bottle makers to stop using the chemical in question—bisphenol A, better known as BPA. Nor is the FDA alone. The Environmental Protection Agency's administrator Lisa Jackson testified to Congress last September that her agency lacks the muscle to restrict the manufacture of BPA and other chemicals. The relevant law, the Toxic Substances Control Act of 1976, is simply too weak. It must be strengthened.

As the law stands, the EPA cannot be proactive in vetting chemical safety. It can require companies to test chemicals thought to pose a health risk only when there is explicit evidence of harm. Of the 21,000 chemicals registered under the law's requirements, only 15 percent have been submitted with health and safety data—and the EPA is nearly powerless to require such data. The law allows companies to claim confidentiality about a new chemical, preventing outside evaluation from filling this data gap; some 95 percent of new submissions fall under this veil of secrecy. Even when evidence of harm is clear, the law sets legal hurdles that can make action impossible. For instance, federal courts have overturned all the EPA's attempts to restrict asbestos manufacture, despite demonstrable human health hazard.

Consequently, of the more than 80,000 chemicals in use in the U.S., only five have been either restricted or banned. Not 5 percent, *five*. The EPA has been able to force health and safety testing for only around 200.

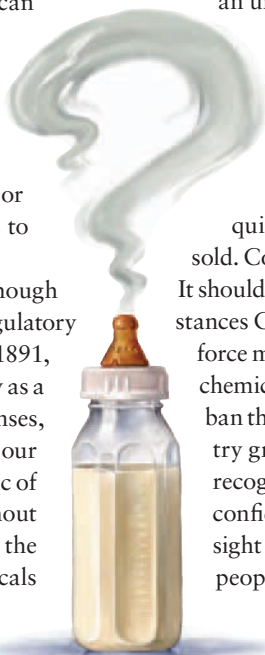
BPA is a case study of what has gone wrong. Although scientists identified potential problems decades ago, regulatory changes have been slow to follow. First synthesized in 1891, the compound became essential to the plastics industry as a building block of the polycarbonates in our eyeglass lenses, the polyesters in our clothes and the epoxy resins lining our cans. In the 1930s BPA was identified as a potent mimic of estrogen; it could bind to the same receptors throughout the human body as the natural female hormone. But the Toxic Substances Control Act explicitly allowed chemicals already employed at the time of the law's passage—BPA and more than 60,000 others—to continue

to be used without any evaluation for toxicity or exposure limits.

Nor did the act give the EPA the power to reevaluate chemicals in light of new information—such as the concerns about BPA that emerged in the 1990s. Researchers in a genetics laboratory noticed that a control population of mice developed an unusually high number of chromosomally abnormal eggs. The reason? BPA leaching from their plastic cages. From this serendipitous discovery, scientists began to explore anew BPA and other chemicals like it, known collectively as endocrine disruptors. Studies since then have linked BPA to asthma, behavioral changes, some cancers, cardiovascular disease, diabetes and obesity. The National Toxicology Program warned in 2008 that “the possibility that bisphenol A may alter human development cannot be dismissed.” Some health effects from BPA may even be passed from one generation to the next, and in contradiction to textbook toxicology, low doses of BPA may be as harmful as high doses. The Centers for Disease Control and Prevention has found that 93 percent of Americans have detectable levels of BPA by-products in their urine.

This problem is not confined just to BPA. New evidence is emerging about the dangers posed by the chemicals used to make plastics flexible or retard burning, among others. Although most chemicals are presumably safe, the lack of testing and ongoing bureaucratic delay imposed by existing legal requirements pose an unreasonable risk. It should not take decades for government agencies to catch up with the latest findings of science.

So the EPA is gearing up to try to regulate chemicals, establishing a list of “chemicals of concern” that echoes a similar list developed by regulators in the European Union under a recent law requiring that chemicals be tested for safety before being sold. Congress has begun to debate how to support this effort. It should begin by reforming and strengthening the Toxic Substances Control Act to require reviews of chemicals for safety, force manufacturers to provide adequate health data on any chemical under review, and empower agencies to restrict or ban the use of chemicals with clear evidence of harm. Industry groups such as the American Chemistry Council have recognized that such measures are needed to ensure public confidence in their products. Ultimately, the goal of oversight is simply to reflect the best available science, so that people are protected from the demonstrable risks posed by chemicals such as BPA and can rest assured that the chemicals industry says are safe really are. ■



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Expert Systems Fight Poverty

Appropriate information and communications technologies, combined with community involvement, can save lives

BY JEFFREY D. SACHS



In his wonderful new book *The Checklist Manifesto* (Metropolitan Books, 2009), surgeon and author Atul Gawande explains how successful surgery depends on the complex interactions of surgeons, nurses, anesthetists and other specialists, who must possess not only highly specialized skills

but also the ability to work as a team in the face of rapidly arising challenges. The same applies to an airliner's pilot, co-pilot and crew. Special tools such as checklists, decision trees and artificial intelligence built into instrumentation are key.

Information technology empowers complex group processes in striking new ways, but the breakthroughs are especially exciting in very low income settings. There mobile telephony and wireless broadband are ending the grinding isolation of rural communities and enabling workers—even those with fairly rudimentary training—to interconnect more successfully and to tap into expert systems and artificial intelligence.

On a recent trip to Africa, I saw two simple but powerful examples of lifesaving protocols enabled by mobile phones. In the Ghanaian village of Bonsaaso, part of the Millennium Village Project, a simple phone-based system is lowering maternal mortality during childbirth. Community health workers (CHWs) with basic training, a skilled midwife, an ambulance driver and a receiving hospital use mobile phones to coordinate as a team. Ever more deliveries now take place in the clinic rather than at home; in the event of complications, the mother is whisked to a receiving hospital about 10 miles away. Mobile phone connectivity among community, clinic, ambulance and hospital makes possible a once unthinkable degree of coordination.

In the Kenyan village of Sauri, also part of the Millennium Village Project, CHWs are pioneering the application of expert systems for malaria control. In the past, suspected malaria patients had to walk or be carried to a clinic, often miles away, have a blood smear read under a microscope by a trained technician and, if positive, receive a prescription. With clinics few and far between and with trained technicians and microscopes even scarcer, untreated, lethal malaria ran rampant.

In the new approach, CHWs visit households on the lookout for fevers that may signify malaria. They carry rapid diagnostic tests that examine a drop of blood for the presence of the malaria pathogen. Then they send an SMS (short service message) text

with the patient's ID and the test results. Seconds later an automated text response informs the health worker of the proper course of treatment, if any. The system can also send reminders about any follow-up treatments or scheduled clinic visits for the patient. The new system of malaria control includes insecticide-treated bed nets made to last for five years and a new generation of combination drugs based on a traditional Chinese herbal treatment, artemisinin.

This full set of tools constitutes a remarkably effective malaria-control system. Already a partial deployment of the system is reducing the malaria burden dramatically in several parts of Africa. Modest international financial support could greatly accelerate the deployment of the full system, and if it were scaled up throughout Africa, hundreds of thousands of lives could be saved annually at around \$7 per person a year in the malaria-transmission zones.

India is similarly scaling up rural public health by deploying advanced information technologies, CHWs and improved management systems. In the past, public health data became available only after rounds of surveys three years apart, and those results were used mainly for research purposes. Now key data will increasingly be available after only hours or days and will be used for real-time health system management.

Checklists, teamwork and telecommunications-based expert systems can revolutionize rural farm yields, disease control, business networks, rural finance, education systems, and much more. Soon farmers will be able to enter local data for advice on specific soil needs, timing on the planting season, drought and rainfall forecasts, market prices and logistics. Mobile-phone-based banking and payments services will penetrate even the most remote regions. With development aid directed toward these new systems, the world's capacity to reduce poverty, hunger and illness—and the violence that accompanies them—will become more powerful and effective than ever. ■

Jeffrey D. Sachs is director of the Earth Institute at Columbia University (www.earth.columbia.edu).



An extended version of this essay is available at www.ScientificAmerican.com/apr2010

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The Sensed-Presence Effect

How the brain produces the sense of someone present when no one is there

BY MICHAEL SHERMER



In the 1922 poem *The Waste Land*, T. S. Eliot writes, cryptically: *Who is the third who always walks beside you?/When I count, there are only you and I together /But when I look ahead up the white road/There is always another one walking beside you.*

In his footnotes to this verse, Eliot explained that the lines “were stimulated by the account of one of the Antarctic expeditions [Ernest Shackleton’s] ... that the party of explorers, at the extremity of their strength, had the constant delusion that there was *one more member* than could actually be counted.”

Third man, angel, alien or deity—all are sensed presences, so I call this the sensed-presence effect. In his gripping book, *The Third Man Factor* (Penguin, 2009), John Geiger documents the effect in mountain climbers, solo sailors and ultraendurance athletes. He lists conditions associated with it: monotony, darkness, barren landscapes, isolation, cold, injury, dehydration, hunger, fatigue and fear. I would add sleep deprivation; I have repeatedly experienced its effects and witnessed it in others during the 3,000-mile nonstop transcontinental bicycle Race Across America. Four-time winner Jure Robic, a Slovenian soldier, recounted to the *New York Times* that during one race he engaged in combat a gaggle of mailboxes he was convinced were enemy troops; another year he found himself being chased by a “howling band” of black-bearded horsemen: “Mujahedeen, shooting at me. So I ride faster.”

Sleep deprivation also accounts for Charles A. Lindbergh’s sensed presence during his transatlantic flight to Paris: “The fuselage behind me becomes filled with ghostly presences—vaguely outlined forms, transparent, moving, riding weightless with me in the plane ... conversing and advising on my flight, discussing problems of my navigation, reassuring me, giving me messages of importance unattainable in ordinary life.”

Whatever the immediate cause of the sensed-presence effect, the deeper cause is to be found in the brain. I suggest four explanations: 1) The hallucination may be an extension of the normal sensed presence we experience of real people around us, perhaps triggered by isolation. 2) During oxygen deprivation, sleep deprivation or exhaustion, the rational cortical control over emo-

tions shuts down, as in the fight-or-flight response, enabling inner voices and imaginary companions to arise. 3) The body schema, or our physical sense of self—believed to be located primarily in the temporal lobe of the left hemisphere—is the image of the body that the brain has constructed. If for any reason your brain is tricked into thinking that there is another you, it constructs a plausible explanation that this other you is actually another person—a sensed presence—nearby. 4) The mind schema, or our psychological sense of self, coordinates the many independent neural networks that simultaneously work away at problems in daily living so that we feel like a single mind.

Neuroscientist Michael S. Gazzaniga of the University of California, Santa Barbara, calls this the left-hemisphere interpreter—the brain’s storyteller that pulls together countless inputs into a meaningful narrative story. In an experiment with a “split-brain” patient (whose brain hemispheres were surgically disconnected), Gazzaniga presented the word “walk” only to the right hemisphere. The patient got up and began walking. When he was asked why, his left-hemisphere interpreter made up a story to explain this behavior: “I wanted to go get a Coke.”

My brother-in-law Fred Ziel, who has twice climbed Mount Everest, tells me that both times he experienced a sensed presence: first when he was frostbitten and without oxygen at the limit of physical effort above the Hillary Step, and second on Everest’s north ridge after he collapsed from dehydration and hypoxia at 26,000 feet. Both times he was alone and feeling desirous of company. Tellingly, when I asked his opinion as a medical doctor on possible hemispheric differences to account for such phenomena, Fred noted, “Both times the sense was on my right side, perhaps related to my being left-handed.” The sensed presence may be the left-hemisphere interpreter’s explanation for right-hemisphere anomalies.

Whatever its cause, the fact that it happens under so many different conditions tells us that the presence is inside the head and not outside the body. ■

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com) and author of *How We Believe*.



Dark Matters

Sometimes the pursuit of a great discovery is its own reward

BY LAWRENCE M. KRAUSS



Even as scientists and politicians from around the world debated in December how to deal with a practical problem of profound importance—global climate change—another international group of physicists was waiting with bated breath for a more esoteric development. In both cases, at the conclusion of events, the participants were left salivating and unsatisfied.

The Cryogenic Dark Matter Search (CDMS) experiment, located in the deep Soudan mine in Minnesota, is designed to directly detect new elementary particles that might make up the dark matter known to dominate our galaxy. In early December rumors started circulating that the CDMS experiment might actually have seen a signal.

To appreciate the significance of such an event, one needs to recognize that scientists have spent the past 40 years building a magnificent theoretical house of cards that could have toppled with the slightest whiff of inconsistent data. In the 1970s evidence began to accumulate from observations of our galaxy's rotation that there was perhaps 10 times as much invisible as visible material out there. Although mundane explanations for such material—from snowballs to planets to cold gas—at first seemed possible, gradually it became clear that none of these could fit the bill. Meanwhile independent calculations of the abundance of light elements expected to be produced in the first minutes after the big bang implied that the universe simply lacked enough protons and neutrons to account for this dark matter if the predictions were to agree with observations.

Similarly independent computer calculations about the formation of galaxies as the universe expanded suggested that only some new kind of material, which did not interact as normal matter does, could collapse early enough to lead to the structures we see.

The past 50 years of particle physics has also driven us to realize that for what we see to make sense, a host of new elementary particles quite likely exists. If so, theorists have determined that the earliest moments of the fiery big bang could have produced these particles in precisely the abundance to account for dark matter, and their interactions with normal matter would have been weak enough to make them invisible to telescopes today.

Egged on by the suggestion that such new dark matter particles in our galactic halo might be directly detectable, a brave set of experimentalists began to devise techniques to observe them with detectors deep underground, far from the reach of most cosmic rays that would overwhelm such acute sensors.

When we first proposed those experiments more than 25 years ago, I had expected that within a decade we would have the answer. But technologies at the forefront take time to build and develop, and nature rarely reveals its secrets willingly.

So after a generation of anticipation, when the physics community heard rumors that the CDMS experiment had detected something, we tuned in to the online announcement as if it were a Beatles reunion concert. It is an unreal feeling, if you are a theorist like me, to imagine that nature might actually obey the delicate theories and fanciful ideas you develop at your desk late at night on scraps of paper or at a computer screen.



The actual announcement was disappointing, however: just two pulses were detected over almost a year, and they *might* have been caused by dark matter. Unfortunately, there was also about a 25 percent chance that the events were instead caused by background radioactivity.

I admit to feeling let down at the time, but months later it is easier to regain perspective. Within a year bigger detectors will turn on, and they may yet confirm the present hints to be real signals. Moreover, the hypothesized particles might yet be detected if collisions can create them at CERN's Large Hadron Collider.

If these experiments pan out, the result won't yield a better toaster or solve the problems of climate change. But it will provide remarkable vindication of the power of human imagination, combined with rigorous logic and technological know-how, to uncover hidden worlds that even half a century ago could not have been conceived. And if not, we will all just have to work harder to solve the mystery of dark matter. New challenges bring new inspiration, which isn't such a bad thing, either. ■

Lawrence M. Krauss, a theoretical physicist and science commentator, is Foundation Professor and director of the Origins Initiative at Arizona State University (www.krauss.faculty.asu.edu).

Wonders of the Solar System

Artist Ron Miller takes us on a journey to eight of the most breathtaking views that await intrepid explorers of our solar system. The scale of these natural wonders dwarfs anything Earth has to offer. What might we see and feel if we could travel to these distant domains? The artist's eye—interpreting data from probes such as NASA's Cassini, which is now exploring the Saturnian system, and MESSENGER, which has flown by Mercury three times and goes into permanent orbit next March—allows us an early visit to these unforgettable locales.

By Edward Bell

ILLUSTRATIONS BY RON MILLER

1

THE RINGS OF SATURN

YOU ARE CRUISING in the troposphere of Saturn under the most magnificent ring structure in the solar system. Few sights are more astounding. The white, icy rings soar 75,000 kilometers above your head. Ring shine illuminates everything around you. No fewer than six crescent moons rise in the sky. The light from the setting sun scatters against a mist of ammonia crystals, forming a sun dog. You are buffeted by ammonia clouds that stream by you at speeds greater than 1,500 kilometers an hour. These are some of the fastest winds in the solar system. More than 30,000 kilometers below you, with pressures no human-made thing could survive, is a global ocean of liquid metallic hydrogen. There will be no landing on this planet.

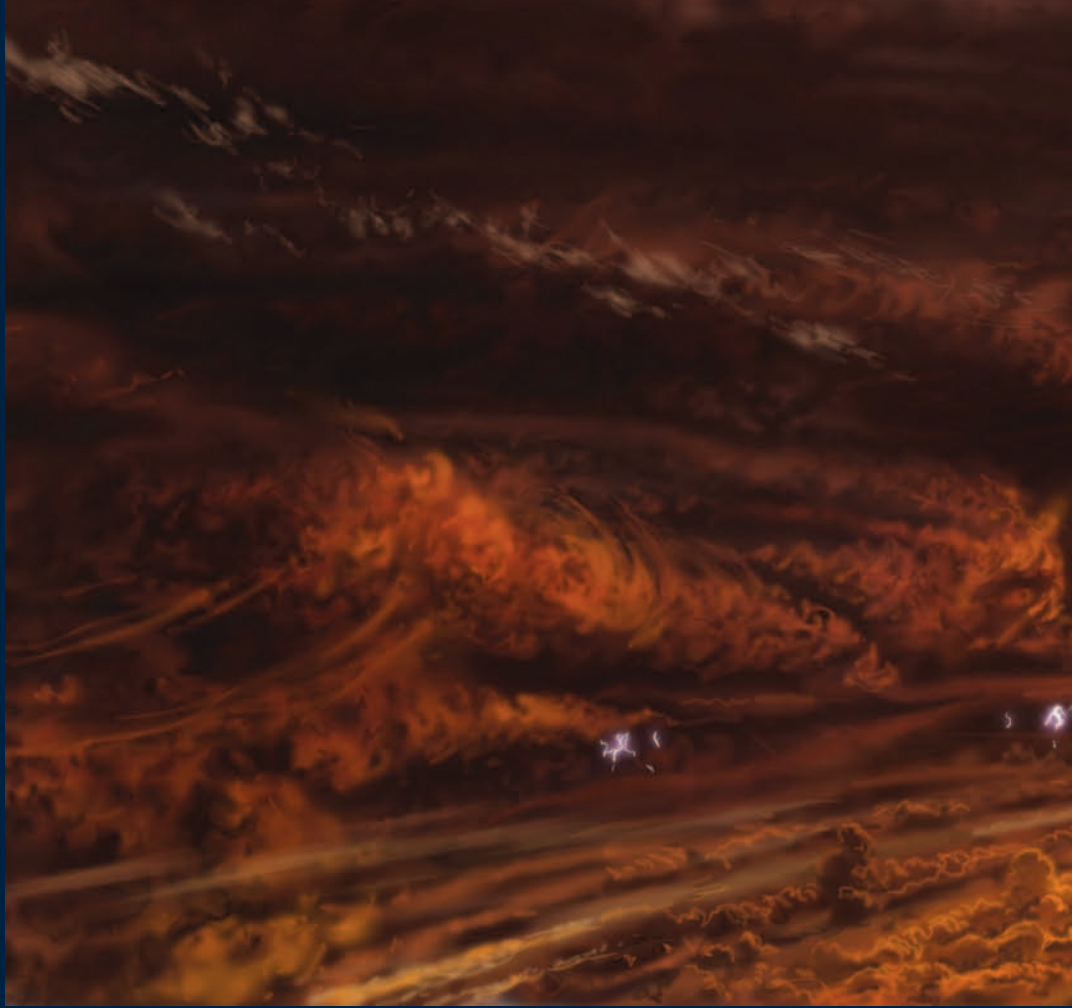




2

JUPITER'S RED SPOT

SHEER SCALE of the solar system's largest anticyclone is difficult for a traveler to grasp. From this vantage point, only a small part of Jupiter's Great Red Spot (*left*) can be seen. It rises at least eight kilometers above the surrounding clouds. Lightning bolts that could pulverize a city crackle at its base into the lower clouds. Winds at the outer edge of the anticyclone swirl at more than 400 kilometers an hour. The spot completes a full counterclockwise rotation once every seven days. The turbulence created by this mega storm is brutal, the sound, deafening. At least two planets the size of Earth could fit inside this monstrous storm, which has been spinning in Jupiter's southern hemisphere for at least 400 years. There is no sign that it will stop.





3

VALLES MARINERIS, MARS

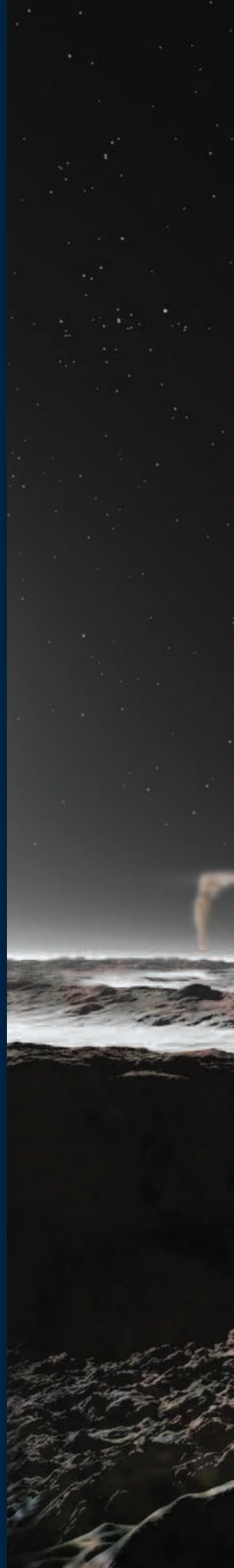
PEOPLE HAVE BEEN KNOWN to fall to their knees and weep at the sight of Arizona's Grand Canyon. One wonders what the first traveler to the Mariner Valley will do when gazing into this canyon. At almost six and a half kilometers deep and so wide that in some places you would have to strain to see the other side, this gigantic tectonic crack would span the U.S. from New York to California—a quarter of the way around the planet—so that sunrise at one end happens six or so hours before sunrise at the other. Water once ran through large segments of this expanse. In this image the traveler views an icy mist filling the valley as the sun sets over the north rim.



4

THE GEYSERS OF ENCELADUS

YOU FEEL IT before you see it: an ominous rumble, reverberating deep in your chest and up from your feet. There is no sound here. And then the eruption comes: two huge ice plumes explode through the surface of Enceladus, spewing ice crystals into space at more than 1,600 kilometers per hour. The silent violence is lit by our distant sun. With just $\frac{1}{16}$ of our own moon's gravity, Enceladus, Saturn's sixth-largest moon, will not be an easy world to tread on; hikers may need to strap on jetpacks and take care to avoid the valleys that give birth to the powerful geysers.



5

THE GEYSERS OF TRITON

VISITORS TO THE LARGEST of Neptune's moons, Triton, will be treated to an array of cryogeysers that are probably composed of nitrogen frost and dark organic compounds. The smoky-looking geysers might be heard from kilometers away as they stream more than 8,000 meters into the thin atmosphere before their tops are whisked away by prevailing winds. Methane and nitrogen ice cover this world whose surface temperature plummets to almost -200 degrees Celsius.



6

PEAKS OF ETERNAL LIGHT

NOT FAR FROM HOME, on our own moon, a unique condition exists (*below*). Discovered in 1994 on Peary crater near the north pole, the so-called peaks of eternal light are the only known region in the solar system where the sun never sets. (Other such regions may exist on Mercury but have not been seen yet.) This unusual condition arises because the moon's rotational axis is barely tilted relative to the plane of its and Earth's orbit around the sun. Certain to become a tourist attraction, this site may one day also house the first moon base. Temperatures in the area fluctuate comparatively little, perhaps by 20 degrees, making it an ideal place to settle. The possibility of water ice here is an added bonus.

7

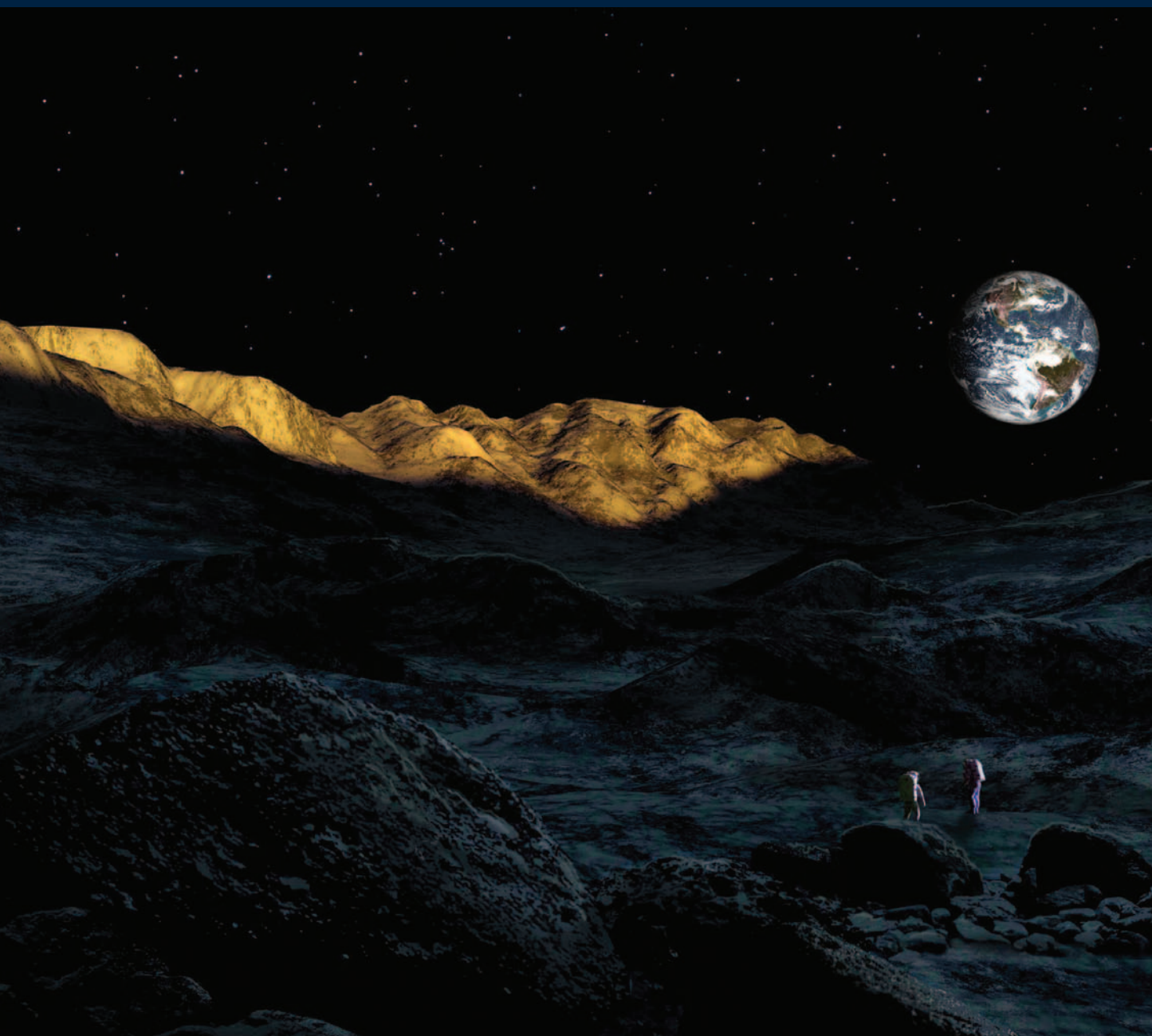
HERSCHEL CRATER ON MIMAS

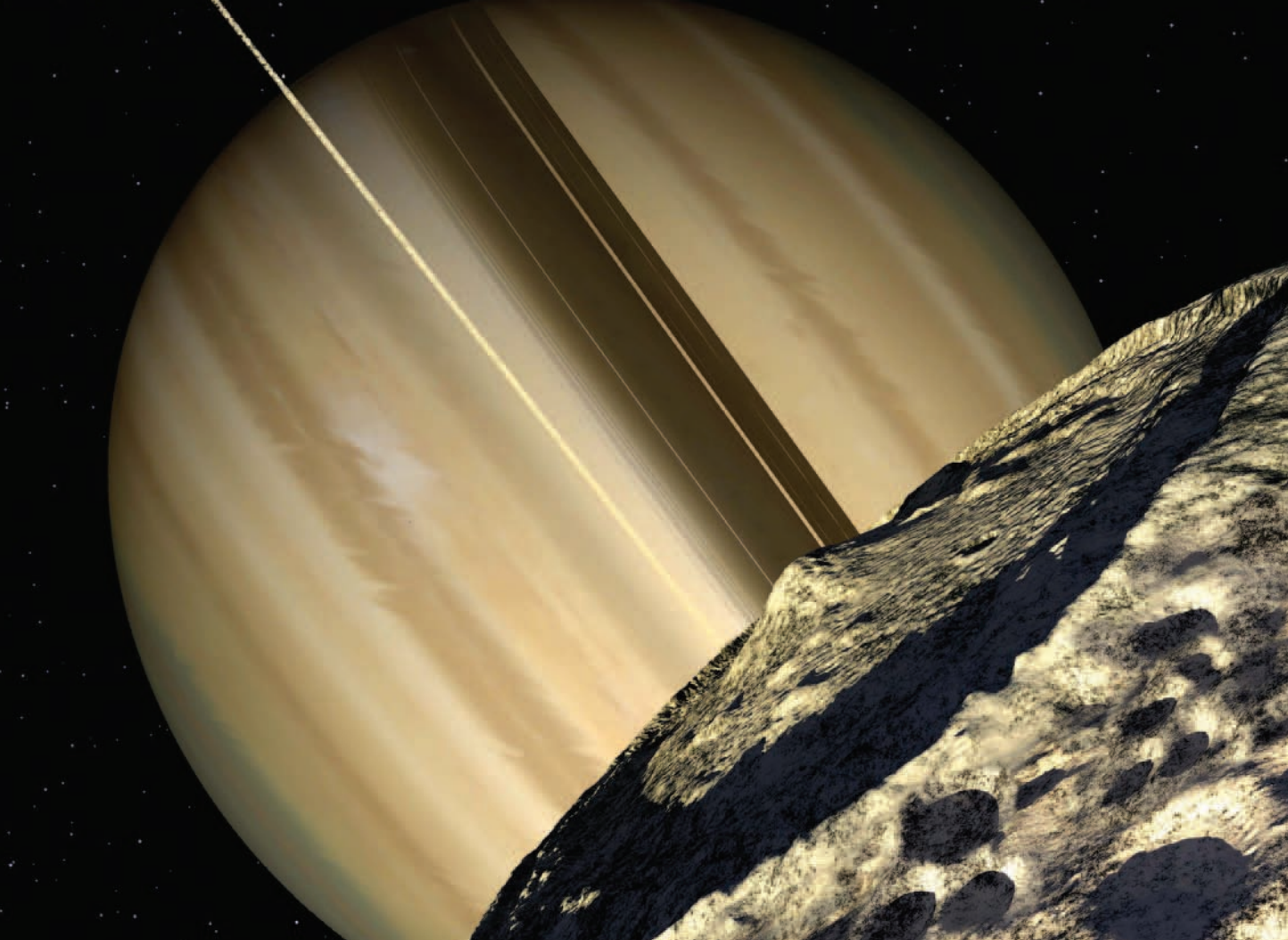


Mimas

ADVENTUROUS CLIMBERS who ascend the peak at the center of Herschel crater on Saturn's moon Mimas (*left*) will find themselves more than 6,000 meters above the basin's floor. Surrounded by the crater walls, which rise to almost 5,000 meters, and with Saturn setting in the background (*right*), travelers might wonder how Mimas survived the impact that formed this 13-kilometer-wide depression, which is almost a third of the satellite's diameter.

NASA





8 SUNRISE ON MERCURY

SUNRISE AND SUNSET on Mercury are spectacles to behold. Two and one half times larger in the sky than seen on Earth, the sun appears to rise and set twice during a Mercurian day. It rises, then arcs across the sky, stops, moves back toward the rising horizon, stops again, and finally restarts its journey toward the setting horizon. These aerial maneuvers occur because Mercury rotates three times for every two orbits around the sun and because Mercury's orbit is very elliptical.



[THE ILLUSTRATOR]

Ron Miller is an author and illustrator with more than 40 books to his credit, including *The Grand Tour* and *Cycles of Fire*, both written with planetary scientist and artist William K. Hartmann. He is a former author for this magazine ("Jules Verne, Misunderstood Visionary," in April 1997) and a winner of the Hugo Award for his science fiction and of the Rudaux Memorial Award from the International Association of Astronomical Artists.

[THE AUTHOR]

Edward Bell is art director of *Scientific American*.

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FAULTY CIRCUITS

Neuroscience is revealing the malfunctioning connections underlying psychological disorders and forcing psychiatrists to rethink the causes of mental illness

By Thomas R. Insel

KEY CONCEPTS

- Because mental disorders such as depression display no conspicuous brain damage, they were long thought to stem from purely psychological processes.
- Neural imaging is revealing that abnormal activity along a circuit of brain structures involved in mental processing underlies many mental disorders, making the physical dysfunction causing the mental symptoms visible for the first time.
- Understanding the biology of mental disorders will clarify the sources of malfunction in a circuit, provide objective methods of diagnosis and lead to targeted treatments.

—The Editors

In most areas of medicine, doctors have historically tried to glean something about the underlying cause of a patient's illness before figuring out a treatment that addresses the source of the problem. When it came to mental or behavioral disorders in the past, however, no physical cause was detectable so the problem was long assumed by doctors to be solely "mental," and psychological therapies followed suit. Today scientific approaches based on modern biology, neuroscience and genomics are replacing nearly a century of purely psychological theories, yielding new approaches to the treatment of mental illnesses.

Many illnesses previously defined as "mental" are now recognized to have a biological cause: in autism, for example, it is an abnormality in the connections between neurons, often attributable to genetic mutations; schizophrenia is now viewed and treated as a developmental brain disorder. Yet the public and even clinicians have had difficulty accepting that certain other mental disorders such as depression, obsessive-compulsive disorder (OCD) or post-traumatic stress disorder (PTSD) could also be physiological disorders of the brain.

A primary reason that the understanding of such mental disorders has lagged so far behind other areas of medicine is that unlike classical

neurological illnesses such as Parkinson's disease or the aftermath of a stroke, where the damage is visible, mental disorders are not marked by conspicuous lesions in the brain—a physical cause is still not obvious. The newest imaging technologies for mapping function in the living brain, though, allow the detection of problems with activity levels in, or communication between, brain areas, even when there is no observable loss of cells.

Neuroimaging has opened up the black box of the brain so that mental disorders can, for the first time, be studied as abnormalities in the connections between distant areas of the brain or, in some cases, problems in the coordination of brain areas whose activity is normally synchronized. Brain regions that function together to carry out normal mental operations can be thought of as analogous to electrical circuits. And the latest research shows that the malfunctioning of entire circuits may underlie many mental disorders.

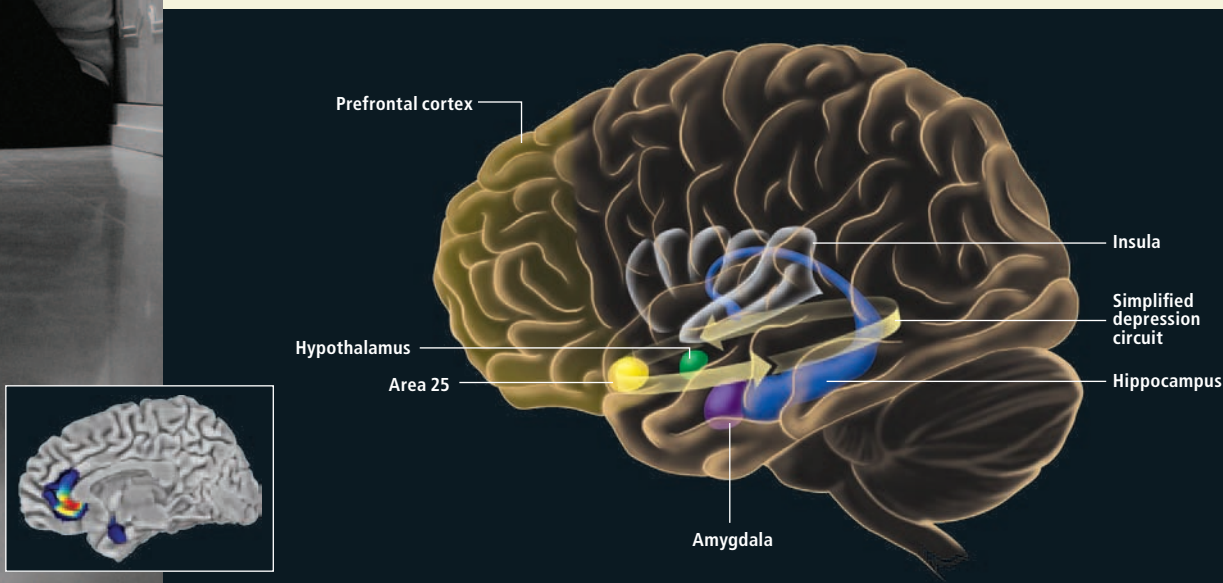
The details of each disorder's "circuit diagram" or map are still emerging. But this new view is already producing seismic shifts in psychiatry, opening avenues to more empirical diagnosis of mental illnesses and providing insights into their underlying causes, which promises more effective forms of treatment.



GOVERNOR OF MOOD



Depression sufferers have low energy and mood, and their reaction times and memory formation are inhibited, as though normal brain activity levels are suppressed. Yet common symptoms, such as anxiety and sleep disturbances, suggest certain brain areas are overactive. Imaging of the brain regions most disrupted in depression points to the source of such imbalances as a tiny brain structure called area 25, which acts as a hub for a depression circuit. Area 25 connects directly to structures such as the amygdala, which mediates fear and anxiety, and the hypothalamus, involved in stress responses. Those regions, in turn, exchange signals with the hippocampus, a center of memory processing, and the insula, where sensory perceptions and emotions are processed. A smaller than normal area 25 (*red in inset*) is suspected of contributing to a higher risk of depression in people with a gene variant that inhibits serotonin processing.



Stuck in Overdrive?

Depression offers perhaps the best example of the rapid progress being made in understanding the biology of mental illness. Major depressive disorder, the official diagnostic term for depression, affects 16 percent of all Americans, potentially leading to loss of work, substance abuse and suicide. It is also one of the most prevalent illnesses in the developed world, where it is the leading cause of medical disability among people between the ages of 15 and 44. The symptoms include not only a profound sense of despair with helplessness and hopelessness but also a range of physical symptoms such as loss of appetite, sleep disturbances, constipation and fatigue that is sometimes mixed with agitation. Depression is known to disturb the immune system and multiple hormonal systems and to increase one's risk for cardiovascular disease. Yet despite its widespread effects on the body, depression is fundamentally a brain disorder. And considerable evidence points to a tiny region in the brain's prefrontal cortex (PFC) called area 25 as a hub for the circuitry underlying depression.

The designation "area 25" comes from a Ger-

man neurologist, Korbinian Brodmann, who assigned numbers to various regions of the cortex in his classic 1909 atlas of the human brain. For the past 100 years this hard-to-reach region, which sits deep in the midline at the front of the brain, has garnered little attention. But over the past decade discovery of its critical role in depression has turned area 25 into high-interest real estate among clinical neuroscientists. Helen Mayberg and her colleagues at Emory University, for example, have shown that the region is overly active in depression and that symptom improvement after virtually all forms of treatment, from medication to psychotherapy, is accompanied by decreased activity in this same region.

Other clues also point to area 25 as having a pivotal role in depression. The region is exceptionally rich with serotonin transporters—molecules that manage the amount of the neurotransmitter serotonin available to neurons. (Many antidepressant medications are believed to act on these transporters, enhancing neural signaling through serotonin.) While at the National Institute of Mental Health, Lukas Pezawas, Andreas Meyer-Lindenberg and their col-

SAMI SARKIS/Getty Images (photograph); FROM: 5-HTTLPR POLYMORPHISM IMPACTS HUMAN CINGULATE-AMYGDALA INTERACTIONS: A GENETIC SUSCEPTIBILITY MECHANISM FOR DEPRESSION, BY LUKAS PEZAWAS ET AL., IN NATURE NEUROSCIENCE, VOL. 8, MAY 8, 2005 (brain image); PRECISION GRAPHICS (illustration)

leagues studied brain scans from more than 100 nondepressed individuals to compare those with “short” and “long” variations of the serotonin transporter gene and found only a single but consistent difference in the subjects’ brains. Participants with the short variation of this gene, which causes less of the transporter protein to be manufactured and is believed to confer a higher risk of depression, had reduced brain tissue volume in area 25. Moreover, in the short-variant subjects, the activity of area 25 was functionally uncoupled from that of subcortical brain regions, such as the amygdala.

As a result of this study and others, neuroscientists now think of depression as a circuitry disorder involving abnormal activity in area 25 that disrupts its vast connected network, including the hypothalamus and brain stem, which influence changes in appetite, sleep and energy; the amygdala and insula, which affect anxiety and mood; the hippocampus, which is critical to memory processing and attention; and parts of the frontal cortex, which mediate insight and self-esteem.

The brain, after all, is an information-pro-

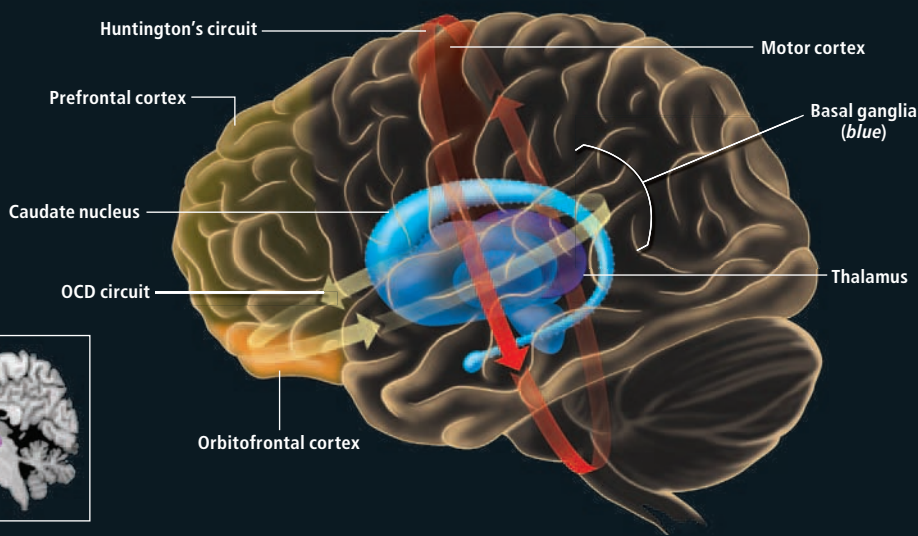
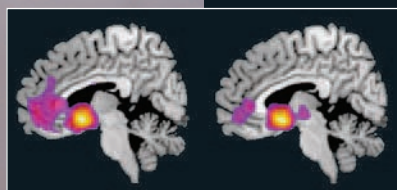
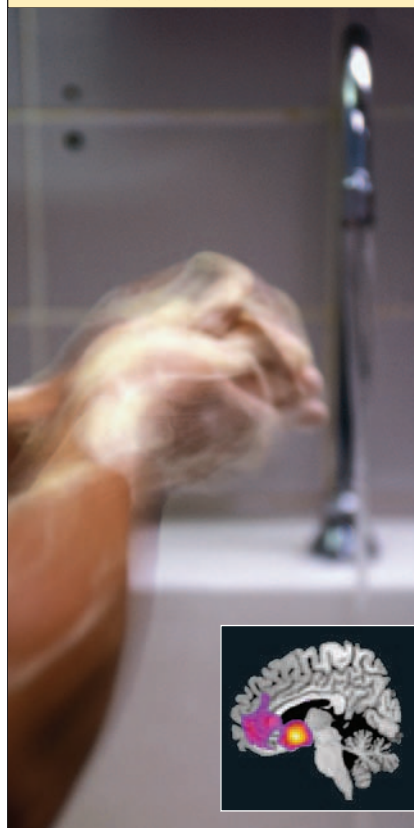
cessing organ, constantly integrating sensory inputs and coordinating responses. To extend the circuitry analogy, area 25 is believed to serve as a governor for a vast network, sensing and modulating the activity levels of other brain centers for fear, memory and self-esteem. A dysfunctional area 25 might therefore fail to coordinate the activity of these other centers so that information processing is biased, leading to distorted assessments of the internal and external world. If this conception is correct, resetting the firing of area 25 should moderate each of these downstream centers, thereby lessening the symptoms of depression. Indeed, Mayberg has demonstrated that direct electrical stimulation near area 25 reduces the activity of this node and can lead to recovery in people with depression who did not respond to standard therapies.

If area 25 can cause the brain, like a computer, to get stuck in a loop of abnormal activity, then the goal of treatment might be akin to “rebooting” a computer that has become frozen. The same principle can be applied to other mental disorders, particularly OCD, which appears even to a casual observer as though the suf-

[OCD CIRCUIT]

A CONSTANT PROD

People with obsessive-compulsive disorder (OCD) liken their intrusive thoughts and powerful urges to perform an action repeatedly to uncontrollable tics. A connection does exist: involuntary movements such as those seen in Huntington’s disease originate in the basal ganglia, a group of structures involved in initiating and coordinating basic motor actions. The caudate nucleus of the basal ganglia is also part of the brain circuit that drives OCD, along with the orbitofrontal cortex, a region critical to decision making and moral judgment, and the thalamus, which relays and integrates sensory information. In OCD sufferers (*left inset*), overactivity is evident in parts of the frontal cortex and basal ganglia, and firing of those regions is more synchronized than in normal subjects (*right inset*).



The goal of treatment might be akin to “rebooting” a computer that has become frozen.

ferer is trapped in a cycle of abnormal thoughts and behaviors.

Relentless Repetition

In an earlier era, obsessive-compulsive disorder was considered the prototypic neurosis, caused by psychic conflict, and ideal for treatment by psychoanalysis. People with OCD suffer from intrusive, repetitive thoughts (obsessions) and may be impaired by the need to perform stereotypic, repetitive rituals (compulsions). Some people may feel they are contaminated and will wash repetitively, to the point of abrading their skin. Others have a nagging sense of having failed to carry out some responsibility and will need to check the stove or the faucets or the doorknobs repeatedly before leaving the house. While people with this condition generally realize that their thoughts are senseless, they cannot control either the obsessions or compulsions, and in severe cases they may become completely disabled.

Patients with OCD often describe their symptoms as “mental tics,” as though they were physical movements that are not under voluntary control. Indeed, many people with OCD have actual tics as well as obsessive thoughts. Most

neuroscientists believe the regulation of movement involves a series of loops in the brain linking the cortex with brain areas such as the basal ganglia, which are centers for initiating and coordinating various aspects of movement. The involuntary motions seen in motor tics or more dramatically in Huntington’s disease reflect abnormal activity in this circuit, usually originating in the basal ganglia. Neuroimaging studies of patients with OCD have discovered abnormal activity in an adjacent loop that includes the orbitofrontal cortex, which is involved in complex tasks such as decision making, the ventral caudate nucleus within the basal ganglia, and the thalamus, which relays and integrates sensory information.

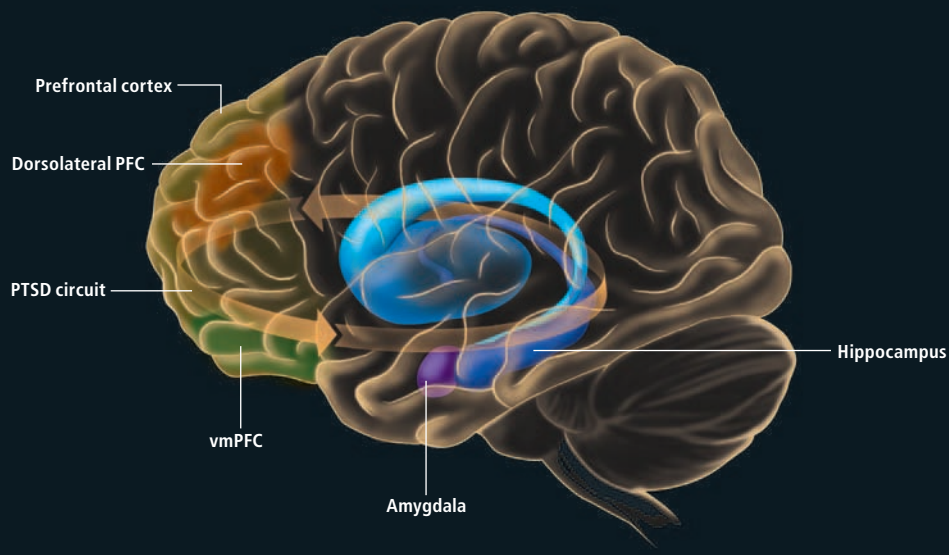
Evidence for overactivity in this circuit in OCD comes from more than just neuroimaging research. Most people with OCD report a profound reduction in symptoms with treatment, whether behavior therapy or medication, and this symptom improvement consistently goes along with a decrease in orbitofrontal cortical activity. In patients who do not respond to medication or behavior therapy, actually disconnecting the orbitofrontal cortex from the cau-

[PTSD CIRCUIT]

PERPETUATOR OF FEAR



In post-traumatic stress disorder (PTSD), cues that evoke a traumatic experience induce fear reactions long after the event. Malfunctioning of a brain structure called the ventromedial prefrontal cortex (vmPFC) is thought to increase vulnerability to the condition because it modulates the amygdala, a driver of fear and anxiety. Normally recovery after trauma, known as extinction, replaces a fear response with a neutral one through a learning process that engages the hippocampus and the dorsolateral prefrontal cortex. The vmPFC is believed to serve as the critical link between the dorsolateral PFC and the amygdala, allowing such extinction learning to quiet the amygdala.



date either by cutting the axons, or nerve fibers, that link them or by inhibiting electrical activity along the fibers also reduces the symptoms of severe OCD. Such a clear effect produced by physically altering the connections within a brain circuit offers strong evidence for the principle that symptoms of mental disorders can arise from the dysfunction of a specific circuit.

The underlying cause of the original circuit malfunction in OCD and other mental disorders is a separate question and may have complex answers. In some cases, a preexisting vulnerability may be present. Just as predispositions to high cholesterol or high blood glucose can run in families, individual genetic variations can influence the brain's development and operation. As in other complex health disorders, however, a genetic vulnerability does not produce illness alone—environment and experiences usually interact with genetic variations and may cause disease in some people but not others. This recognition that the brain's individual biology may interact with experiences to cause or exacerbate disordered circuits is particularly helpful in understanding the aftermath of trauma.

Unlearning Fear

Post-traumatic stress disorder is one of the most common afflictions of veterans returning from war. Once called combat neurosis or battle fatigue, it is now classified as an anxiety disorder that includes disturbing intrusive thoughts, such as flashbacks to a specific traumatic event, nightmares, a high state of vigilance and sleep disturbance. The disorder is also increasingly recognized in nonveterans who are victims of civilian violence such as rape or terrorism and even automobile accidents.

At first glance, PTSD seems unlikely to be a disorder caused by abnormal brain circuitry. Even its name describes the “cause” as an external event—a specific trauma. Symptoms such as disturbed sleep and increased vigilance are to be expected immediately after a traumatic experience, and for most people they naturally fade with time. PTSD, however, develops weeks and months later in about 20 percent of trauma victims. They continue to experience acute stress responses—in essence, intense fear reactions—to memories or other cues evocative of the original trauma.

In psychotherapy, the process of reducing fear is called extinction. It means specifically that through repeated exposure to a particular trauma-related memory or cue, without adverse

consequences, a patient is able to sever that cue from an automatic extreme fear response and to learn a new, neutral response to it. PTSD can thus be considered a failure of extinction. And recovery, whether natural or through therapy, requires new learning. Recent evidence from studies of animals and of people suggests that a dysfunctional circuit may make extinction harder to achieve, leaving a person vulnerable to developing PTSD.

The key hubs in the brain for fear are the amygdala and an adjacent galaxy of cells called the bed nucleus of the stria terminalis. These regions drive virtually all the symptoms of fear: racing heart, increased sweating, freezing and exaggerated startle responses. Nerve cells in the amygdala project their long, slender axons to centers in the brain stem that control those autonomic functions and also to areas in the forebrain that influence motivation, decision making, and the saliency of specific stimuli. But if the amygdala is the engine of fear, something in the brain should be responsible for turning it off when conditions change and fear is no longer necessary or appropriate.

Studies by Greg Quirk and his colleagues at the University of Puerto Rico show that a tiny area within the prefrontal cortex of rodents, known as the infralimbic region, is central to fear extinction. After teaching the animals to be afraid of a certain stimulus and then using extinction training so the animals could overcome their fear, Quirk's group found that activity in the infralimbic area increases during extinction, serving as a brake on the amygdala. Experimental microstimulation of cells in the infralimbic appears to cause extinction behavior, even in animals that have not been trained to overcome their fear. Furthermore, blocking neural function in this tiny prefrontal region impairs extinction in animals that have been trained, suggesting that the activity of this brain region is both necessary and sufficient to overcome fear.

In PTSD sufferers, neuroimaging studies point to abnormal activity in the ventromedial prefrontal cortex (vmPFC), which is comparable to the rat's infralimbic region. Five different studies have found that when exposed to trauma-related cues, people with PTSD show reduced activity in the vmPFC. They also have a smaller vmPFC relative to trauma-exposed control subjects without PTSD. Indeed, Mohammed Milad and his colleagues at Massachusetts General Hospital in a study of healthy volunteers recently reported that the thickness of this region was

[THE AUTHOR]



Thomas R. Insel, a psychiatrist and neuroscientist, is director of the National Institute of Mental Health, the federal agency that supports the study of mental illnesses. His early clinical research revealed the role of serotonin in obsessive-compulsive disorder, and his animal studies of the neurobiology underlying social attachment identified the importance of brain receptors for oxytocin and other substances in forming social bonds. In describing new findings in the neurocircuitry of mood disorders, as in all his work, Insel endeavors to bridge divisions between biology and psychology by highlighting the reciprocal relations between neural activity and behavior.

Studies of circuit functioning have shown not only that certain treatments work but *how* they may work by altering brain activity.

correlated directly with the capacity to extinguish fear memories. Elizabeth Phelps and her colleagues at New York University have demonstrated that extinction learning in humans, just as in rodents, involves an increase in vmPFC activity and a decrease in amygdala activity.

Neuroimaging has begun to identify the biological basis for improvements through cognitive-behavioral therapy, a form of talk therapy that emphasizes changing a patient's responses to difficult situations. The imaging shows the importance of the hippocampus for assessing context and of the dorsolateral prefrontal cortex for learning to tolerate and overcome fear. Because the dorsolateral prefrontal cortex does not connect directly to the amygdala, however, the vmPFC is thought to be the critical link between them that allows cognitive treatment to produce new learning and recovery.

Fundamental Shifts

The examples I have described from studies of people with depression, OCD and PTSD all suggest a correlation between the activity of interconnected regions of the brain and the abnormal behavior and feelings that characterize those disorders. In each case, the prefrontal cortex is involved, which is not surprising. The PFC is a brain region that is less developed in other mammals, which makes it difficult to study in

laboratory animals but also suggests that it is central to what makes us human. Scientists' best estimation is that the PFC acts as an overall governor for the brain and is the place where our most complex goals and motivations are processed so that we can make decisions and plan for the future.

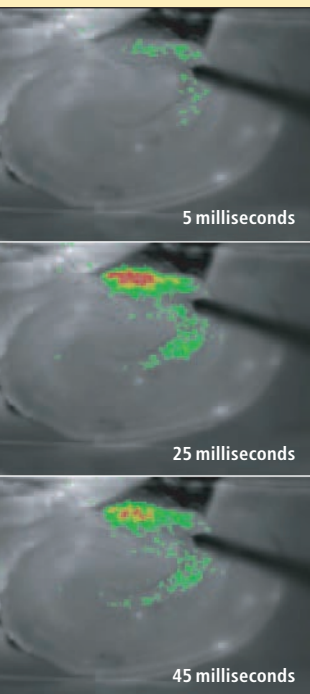
In each of the disorders described, though, a different PFC structure and different connected regions appear to be involved. Beyond these examples, abnormal activity has also been seen in the dorsolateral prefrontal cortex in schizophrenia, and delayed maturation of the entire PFC between the ages of seven and 12 has been seen in attention-deficit hyperactivity disorder.

Although these correlations are compelling, further research is required to establish precisely which aspects of brain activity underlie these and other mental disorders. Data about genes that may increase risk for a given disorder will also help unravel the physiological mechanisms involved.

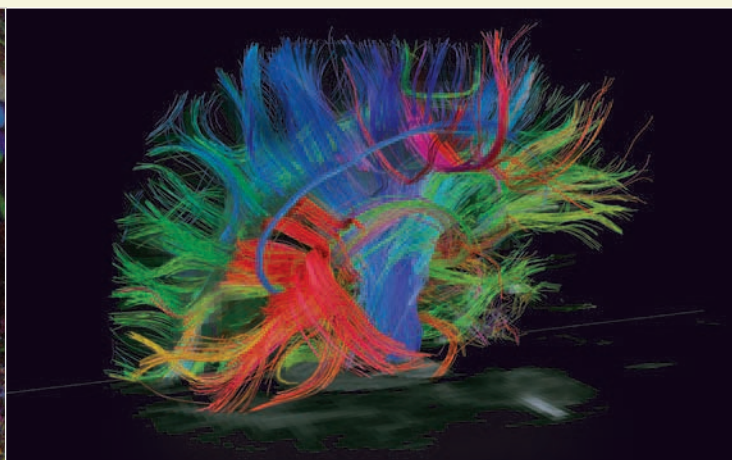
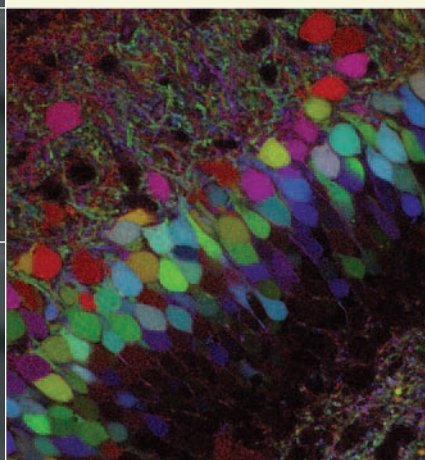
An ability to identify the brain circuit malfunctions underlying mental illness could have broad implications for diagnosis and treatment. At present, mental disorders are classified by their symptoms, which may overlap in many conditions and are not linked to any particular biological evidence. Reclassifying disorders based on brain function could yield a system of diagno-

[IMAGING]

BETTER WINDOWS INTO THE BRAIN



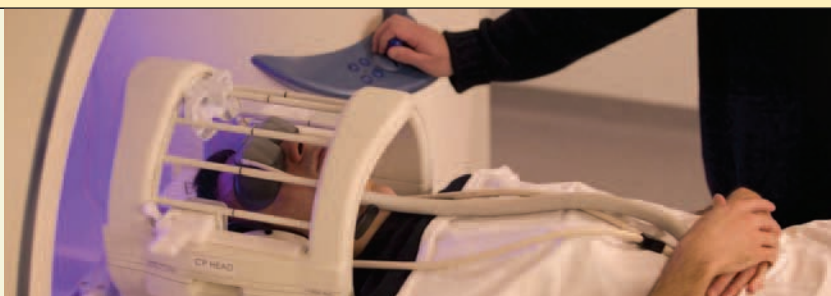
New neural-imaging techniques will expand and refine scientists' understanding of the malfunctions underlying circuit disorders by providing detailed views of brain activity and structure. Voltage-sensitive dye fluoresces red where neural firing is most intense in the hippocampus of a rat (*left panel*). Genetic engineering produces mice whose neurons fluoresce in multiple colors, yielding a "rainbow" picture of developing structures in the mouse brain (*below center*). Diffusion spectrum imaging, which uses MRI data to highlight the nerve fibers connecting different parts of the human brain, can aid in the study of disordered circuits (*below right*).



FROM: HIGH-SPEED IMAGING REVEALS NEUROPHYSIOLOGICAL LINKS TO BEHAVIOR IN AN ANIMAL MODEL OF DEPRESSION, BY KARL DEISSEROTH ET AL., IN SCIENCE, VOL. 317, AUGUST 10, 2007. REPRINTED WITH PERMISSION FROM AAAS (hippocampus); GETTY IMAGES (rainbow); COURTESY OF VAN J. WEDEEN (Massachusetts General Hospital) (connecting fibers)

BRIDGING THE GAP

Disparities between medical treatment of a mental disorder such as depression and that of heart disease, for example, stem from differences in knowledge about the biological underpinnings of disease. Understanding the causes and nature of malfunctioning circuits in mental disorders will make earlier diagnosis possible through brain imaging and potentially blood testing for genetic and protein “markers” that signal a problem. Interventions can then be tailored to address the underlying cause directly and quickly.



DEPRESSION TREATMENT PAST, PRESENT AND FUTURE

	1960	2010	GOAL FOR 2020
Predictors of risk	None	Weak (family history, history of trauma)	Strong (genes, proteins, imaging)
Diagnosis	By interview	By interview	By imaging, biomarkers, interview
Interventions	Institutionalization, electroconvulsive therapy, insulin coma	Antidepressants, cognitive therapy	■ Preventives: cognitive therapy or vaccine ■ Treatment options tailored to individual need: improved medications, cognitive therapy, brain stimulation
Outcomes	Relapse risk high, mortality high	50 percent response after 12 weeks, relapse risk high, mortality high	Response in 24 hours, relapse risk low, mortality low

sis based on biomarkers—biological signs such as brain activity patterns or chemical or structural changes specific to the condition. Just as blood tests of cholesterol or prostate-specific antigen levels and physiological measures such as electrophysiology and imaging scans are used in the rest of medicine, mental disorders could be diagnosed with greater precision and possibly identified earlier by their distinctive biological markers.

Currently a defining criterion for diagnosing schizophrenia is an episode of psychosis, just as heart disease was once defined by a person having suffered a heart attack. For brain disorders, behavioral and cognitive symptoms may be late manifestations of dysfunction in a circuit, and symptoms may appear only after compensatory mechanisms no longer suffice. In Parkinson's, observable symptoms emerge only after 80 percent of the dopamine-producing cells in the substantia nigra deteriorate. In Huntington's, motor problems become evident after 50 percent of basal ganglia neurons are lost.

Interventions will depend on the nature of the disorder. Studies of circuit functioning have shown not only that certain treatments such as cognitive-behavioral therapy work but *how* they may work by altering brain activity, and these insights might be used to improve existing ther-

apy techniques. Many current antidepressant and antipsychotic medications are also effective, but no more so than the drugs available 40 years ago. A better understanding of the physiological malfunctions in the brain underlying depression will likely lead to more targeted and curative treatments.

Perhaps the most immediate result of approaching mental disorders as brain circuit disorders will be changing public perception of these illnesses. In different generations, people with mental illness have been stigmatized as possessed, dangerous, weak-willed or victimized by bad parents. Science supports none of this. A scientific approach to mental disorders could allow those who struggle with these illnesses to receive full acceptance and the high-quality care that they deserve.

From the scientific standpoint, it is difficult to find a precedent in medicine for what is beginning to happen in psychiatry. The intellectual basis of this field is shifting from one discipline, based on subjective “mental” phenomena, to another, neuroscience. Indeed, today's developing science-based understanding of mental illness very likely will revolutionize prevention and treatment and bring real and lasting relief to millions of people worldwide. ■

➔ MORE TO EXPLORE

Targeting Abnormal Neural Circuits in Mood and Anxiety Disorders: From the Laboratory to the Clinic. Kerry J. Ressler and Helen S. Mayberg in *Nature Neuroscience*, Vol. 10, No. 9, pages 1116–1124; September 2007.

Neural Circuitry Underlying the Regulation of Conditioned Fear and Its Relation to Extinction. Mauricio R. Delgado et al. in *Neuron*, Vol. 59, No. 5, pages 829–838; September 11, 2008.

Disruptive Insights in Psychiatry: Transforming a Clinical Discipline. Thomas R. Insel in *Journal of Clinical Investigation*, Vol. 119, No. 4, pages 700–705; April 1, 2009.

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Humankind has fundamentally altered the planet. But new thinking and new actions can prevent us from destroying ourselves

Forget banking and the automotive industry. Earth is the one system that is truly “too big to fail.” For centuries humans have used up the planet’s resources, saddled it with our waste and simply moved on when a wellspring dried up or the back forty became polluted. But now we’ve exhausted that strategy. Scientists, social thinkers and the global public are realizing that humankind has transformed the natural planet into an industrialized one, and we must transition again to a sustainable planet if we are to survive.

So what is the bailout plan? The first step is determining how close to “failure” the world is. On page 54, environmental scientist Jonathan Foley presents the results of a major international collaboration that calculated safe limits for pivotal environmental processes, such as climate change and ocean acidification, that could undermine sustainability if allowed to go too far. The numerical boundaries may need fine-tuning, but knowing which processes matter most tells us where to look for solutions. On page 58, *SCIENTIFIC AMERICAN* invites eight experts to propose specific remedies.

Those fixes could slow environmental degradation but might not solve the underlying cause. That culprit, according to Middlebury College scholar in residence Bill McKibben, is the very driver of modern society: a relentless quest for economic growth. In an exclusive excerpt from his upcoming book, on page 61, McKibben argues that we must give up growth and reorganize based on smart maintenance of resources. Critics say the idea is unrealistic; on page 66, staff editor Mark Fischetti challenges him to respond.

—The Editors

LIVING ON A NEW EARTH

JEN CHRISTIANSEN

Scientists have set thresholds for key environmental processes that, if crossed, could threaten Earth's habitability. Ominously, three have already been exceeded • **BY JONATHAN FOLEY**

BOUNDARIES FOR HEALTHY PLANET

KEY CONCEPTS

- Although climate change gets ample attention, species loss and nitrogen pollution exceed safe limits by greater degrees. Other environmental processes are also headed toward dangerous levels.
- Promptly switching to low-carbon energy sources, curtailing land clearing and revolutionizing agricultural practices are crucial to making human life on Earth more sustainable.

—The Editors

For nearly 10,000 years—since the dawn of civilization and the Holocene era—our world seemed unimaginably large. Vast frontiers of land and ocean offered infinite resources. Humans could pollute freely, and they could avoid any local repercussions simply by moving elsewhere. People built entire empires and economic systems on their ability to exploit what seemed to be inexhaustible riches, never realizing that the privilege would come to an end.

But thanks to advances in public health, the industrial revolution and later the green revolution, population has surged from about one billion in 1800 to nearly seven billion today. In the past 50 years alone, our numbers have more than doubled. Fueled by affluence, our use of resources has also reached staggering levels; in 50 years the global consumption of food and freshwater has more than tripled, and fossil-fuel use has risen fourfold. We now co-opt between one third and one half of all the photosynthesis on the planet.

This wanton growth has also expanded pollution from a local problem to a global assault. Stratospheric ozone depletion and greenhouse gas concentrations are obvious complications, but many other deleterious effects are rising.

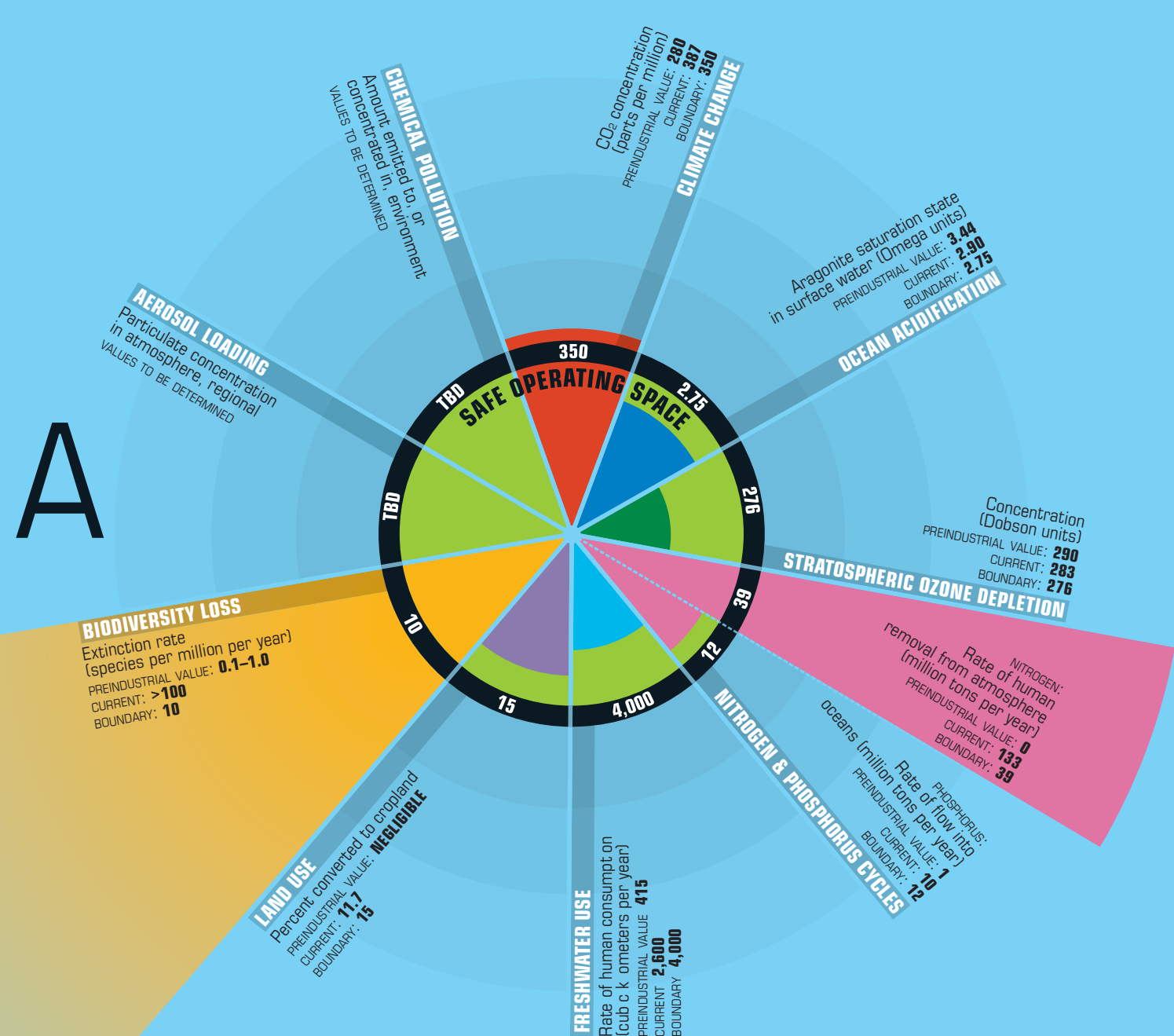
The sudden acceleration of population

growth, resource consumption and environmental damage has changed the planet. We now live in a “full” world, with limited resources and capacity to absorb waste. The rules for living on such a world are different, too. Most fundamentally, we must take steps to ensure that we function within the “safe operating space” of our environmental systems. If we do not revise our ways, we will cause catastrophic changes that could have disastrous consequences for humankind.

What would cause these changes? And how can we avoid them? A worldwide team of scientists—led by Johan Rockström of the Stockholm Resilience Center in Sweden, with colleagues from Europe, the U.S. (including me) and Australia—recently sought answers through a larger, related question: Are we nearing planetary “tipping points” that would push the global environment into dangerous new territory, outside anything seen during human history?

After examining numerous interdisciplinary studies of physical and biological systems, our team determined that nine environmental processes could disrupt the planet's ability to support human life. We then set boundaries for these processes—limits within which humankind can operate safely. Seven of the processes have clear

A



boundaries [see illustration above], scientifically defined by a single number (that of course carries some uncertainty). Three of those boundaries—for climate change, ocean acidification and stratospheric ozone depletion—represent tipping points, and the other four signify the onset of irreversible degradation. The remaining two processes—atmospheric aerosol pollution and global chemical pollution—have not been as extensively studied, so limits are not set yet.

Our group's analysis shows that three processes already exceed their boundaries: biodiversity loss, nitrogen pollution and climate change. And all the others are moving toward the thresholds. Individual limits might be fine-tuned, and others could perhaps be added in the future, but the set represents a "first order" summary of the world's most perilous environmental conditions

and provides a framework for thinking about how to manage the threats.

Fossil-Fuel Complications

Understanding the causes of our most pressing environmental problems offers clues to solving them. In two cases—climate change and ocean acidification—one driver is all too familiar: humankind's use of fossil fuels, which releases carbon dioxide (CO₂) into the atmosphere.

Climate change. Although our planet has already undergone significant human-induced warming and will experience more, scientists and policy makers are seeking ways to avoid the most devastating consequences—including the loss of polar ice sheets, the collapse of freshwater supplies and the disruption of regional weather systems. Already, CO₂ concentration is 387 ppm

PIVOTAL ENVIRONMENTAL PROCESSES should remain within certain limits, otherwise the safe operating space within which humankind can exist will be threatened. Shading represents how far a process has advanced from preindustrial levels toward or beyond a boundary; biodiversity, nitrogen flow and climate change have already crossed their thresholds. (Nitrogen and phosphorus flows are paired because they tend to occur together.)

(by volume, the usual measure), and debate continues over what level of all greenhouse gases would cause dangerous climate change; suggested values range from 350 to 550 ppm of CO₂. In our analysis, we suggest a conservative, long-term target of 350 ppm, to keep the planet well away from climatic tipping points. To meet that target, the world has to take immediate action to stabilize greenhouse gas emissions and, over the next few decades, substantially reduce them below their current levels.

Ocean acidification. The ongoing acidification of the seas is the lesser-known cousin of climate change. As atmospheric CO₂ concentration rises, so does the amount of CO₂ that dissolves in water as carbonic acid, which makes the surface ocean more acidic. The oceans are naturally basic, with a pH of about 8.2, but data show that pH has already slipped to nearly 8.0 and continues to drop. The metric our group used to quantify damage from such change is the falling level of aragonite (a form of calcium carbonate) that is created in the surface layer. Many creatures—from corals to a multitude of phytoplankton that underlie the ocean’s food chain—depend on aragonite to build their skeletons or shells. Increasing acidity could severely weaken ocean ecosystems and food webs, providing another compelling reason for nations to shift toward a low-carbon energy future.

[THE AUTHOR]



Jonathan Foley is director of the University of Minnesota’s Institute on the Environment. Originally trained as an atmospheric scientist, he works primarily on the nexus of land use, agriculture and the global environment.

Food Production Implicated

Humankind already commandeers 35 percent of Earth’s land surface for crops and pastures, and expanding agriculture is the prime motivation for clearing new land, thereby destroying natural ecosystems. Several planetary boundaries are in jeopardy of being crossed because of human land-use practices:

Biodiversity loss. Land development is causing one of the greatest extinctions in Earth’s history. We are losing species 100 to 1,000 times faster than the natural background rates seen in the geologic record. The rate of loss is found across the world’s terrestrial and marine ecosystems and could undermine ecological processes on regional and global scales. Efforts to conserve biodiversity, especially in sensitive tropical forests, need much more attention. Initiatives such as the U.N.’s Reducing Emissions from Deforestation and Forest Degradation program (known as REDD), which develops funding to slow the clearing of tropical forests, can simultaneously address biodiversity decline and carbon emissions and could be very effective.

Nitrogen and phosphorus pollution. Extensive spreading of industrial fertilizers has upset the chemistry of the planet. Fertilizer use has more than doubled the flows of nitrogen and phosphorus through the environment, at a rate of 133 million tons of nitrogen and 10 million tons of phosphorus per year. Both flows are causing widespread water pollution, degrading numerous lakes and rivers and disrupting coastal oceans by creating large, hypoxic “dead zones.” Needed are new agricultural practices that increase food production yet also sustain the environment.

Freshwater depletion. Across the globe, we withdraw a staggering 2,600 cubic kilometers of water annually from rivers, lakes and aquifers, for irrigation (70 percent), industry (20 percent) and domestic use (10 percent). As a result, many large rivers have diminished flows, and some are drying up altogether. Iconic examples include the Colorado River, which no longer reaches the ocean, and the Aral Sea in Central Asia, now largely desert. Future demand could be enormous. Dramatic improvements in the efficiency of global water use, particularly for irrigation, would help avoid even more serious declines.

Stay Far Away

Our group’s initial publication in *Nature* several months ago has generated healthy scientific debate. For the most part, the work has been well received and seen for what it is: a thought

PUSHING THE LIMIT		
Allowing environmental processes to exceed certain limits could have serious repercussions, but decisive actions can keep the processes within safe bounds. [For more, see “Solutions to Environmental Threats,” starting on page 58.]		
ENVIRONMENTAL PROCESS	CONSEQUENCES IF SURPASSED	POSSIBLE SOLUTIONS
Biodiversity loss	Land and ocean ecosystems fail	Slow land clearing and development; pay for ecosystem services
Nitrogen cycle	Freshwater and ocean dead zones expand	Reduce fertilizer use; process animal waste; switch to hybrid vehicles
Phosphorus cycle	Ocean food chains are disrupted	Reduce fertilizer use; process animal waste; process human waste better
Climate change	Polar ice and glaciers melt; regional climates shift	Switch to low-carbon energy and fuels; put a price on carbon emissions
Land use	Ecosystems fail; carbon dioxide escapes	Limit urban sprawl; improve farm efficiency; pay for ecosystem services
Ocean acidification	Microorganisms and corals die; carbon sink lessens	Switch to low-carbon energy and fuels; reduce fertilizer runoff
Freshwater use	Aquatic ecosystems fail; water supplies disappear	Improve irrigation efficiency; install low-flow appliances
Stratospheric ozone depletion	Radiation harms humans, animals and plants	Phase out hydrochlorofluorocarbons; test effects of new chemicals

experiment that attempts to define dangerous “do not cross” lines for the world. We have, however, been roundly criticized by some scientists for even attempting to set boundaries; others do not agree with the numbers we set.

Perhaps the most important comment is that by setting thresholds, we might be encouraging people to think that environmental destruction is acceptable as long as it stays inside the limits. For the record, that is not what we are proposing! Society should not allow the world to drift toward a boundary before acting. Advancing from, say, one third of the way to a boundary to two thirds of the way will still cause severe damage. We urge people to be smart enough and altruistic enough (toward future generations) to stay as far from the limits as possible, because each one represents an environmental crisis.

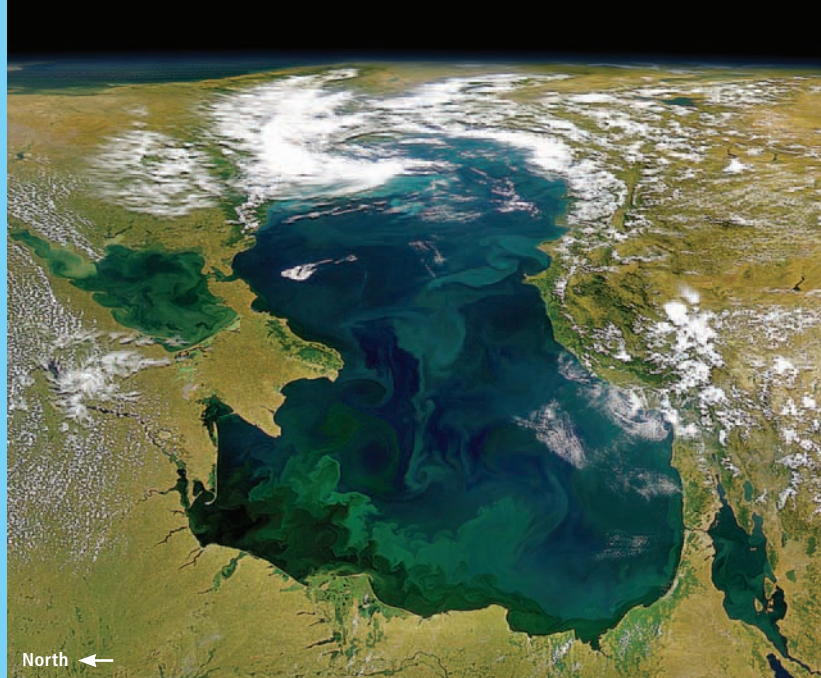
Most criticisms have been reasonable, and our group anticipated many of them. We knew the notion of boundaries would require more study—especially in refining the numbers, which we continue to work on. But we felt the concept was powerful and would help frame collective thinking about environmental limits to human existence. And we hoped the results would stimulate discussion across the scientific community; it appears we have gotten that wish.

A Start at Solutions

A comprehensive set of planetary boundaries should be respected as the world addresses the economic, social and environmental requirements for global sustainability. Society has begun to attack some of the challenges, but only in a piecemeal way, thinking of each boundary independently. But the limits are strongly interconnected. When one threshold is crossed, it puts pressure on others, increasing the risk of breaching them. For example, exceeding the climate change limit may push extinction rates higher. Likewise, nitrogen and phosphorus pollution may undermine the resilience of aquatic ecosystems, greatly accelerating their loss of biological diversity. As well intended as our remedies have been, trying to solve one factor at a time most likely will fail.

In this critical time, it is not enough for scientists to simply define the problems and go home. We must also begin to propose solutions. Here are a few ideas to start with:

- Make the transition to an efficient, low-carbon energy system. The pressing issues of climate change and ocean acidification require



MASSIVE ALGAE BLOOMS (green swirls near bottom) in the Black Sea are spawned by agricultural runoff carried there by the Danube River (bottom), killing aquatic life—an example of the interrelated nature of critical environmental processes, in this case land use and biodiversity.

that we stabilize atmospheric CO₂ concentrations as soon as possible, preferably below 350 ppm. The transition will require massive improvements in energy efficiency, followed by bringing low-carbon energy sources to scale quickly.

- Sharply curtail land clearing and degradation, especially tropical deforestation. Many of the planetary limits, notably biodiversity loss, are compromised by the relentless expansion of human settlements.
- Invest in revolutionary agricultural practices. Several boundaries, including those relating to nutrient pollution and water consumption, are affected by our industrialized agricultural systems. New approaches are possible, including new plant varieties and precision agriculture techniques, as well as far more efficient use of water and fertilizer.

As we implement solutions, we should recognize that no simple rulebook exists for achieving a more sustainable future. We will develop new working principles as we go for our economic systems, political institutions and social actions, remaining acutely aware of our limited understanding of environmental and human processes. Any benchmarks or innovative practices should allow us to react to changing indicators of environmental health and social needs, while helping us enhance the resilience of natural and human systems so that they are more robust and less vulnerable to unexpected shocks that very likely will occur. To maximize that resiliency, we will have to do our best to live within the boundaries of a shrinking planet. ■

➔ MORE TO EXPLORE

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SOLUTIONS TO ENVIRONMENTAL

Experts tell **SCIENTIFIC AMERICAN** which actions will keep key processes

BIODIVERSITY LOSS

Gretchen C. Daily, professor of environmental science, Stanford University



It is time to confront the hard truth that traditional approaches to conservation, taken alone, are doomed to fail. Nature reserves are too small, too few, too isolated and too subject to change to support more than a tiny fraction of Earth's biodiversity. The challenge is to make conservation attractive—from economic and cultural perspectives. We cannot go on treating nature like an all-you-can-eat buffet.

We depend on nature for food security, clean water, climate stability, seafood, timber, and other biological and physical services. To maintain these benefits, we need not just remote reserves but places everywhere—more like "ecosystem service stations."

A few pioneers are integrating conservation and human development. The Costa Rican government is paying landowners for ecosystem services from tropical forests, including carbon offsets, hydro-power production, biodiversity conservation and scenic beauty. China is investing \$100 billion in "ecocompensation," including

innovative policy and finance mechanisms that reward conservation and restoration. The country is also creating "ecosystem function conservation areas" that make up 18 percent of its land area. Colombia and South Africa have made dramatic policy changes, too.

Three advances would help the rest of the world scale such models of success. One: new science and tools to value and account for natural capital, in biophysical, economic and other terms. For example, the Natural Capital Project has developed InVEST software that integrates valuation of ecosystem services with trade-offs, which governments and corporations can use in planning land and resource use and infrastructure development. Two: compelling demonstrations of such tools in resource policy. Three: cooperation among governments, development organizations, corporations and communities to help nations build more durable economies while also maintaining critical ecosystem services.

NITROGEN CYCLE

Robert Howarth, professor of ecology and environmental biology, Cornell University

Human activity has greatly altered the flow of nitrogen across the globe. The single largest contributor is fertilizer use. But the burning of fossil fuels actually dominates the problem in some regions, such as the northeastern U.S. The solution in that case is to conserve energy and use it more efficiently. Hybrid vehicles are another excellent fix; their nitrogen emissions are significantly less than traditional vehicles because their engines turn off while the vehicle is stopped. (Emissions from conventional vehicles actually rise when the engine is idling.) Nitrogen emissions from U.S. power plants could be greatly reduced, too, if plants that predate the Clean Air Act and its amendments were required to comply; these plants pollute far out of proportion to the amount of electricity they produce.

In agriculture, many farmers could use less fertilizer, and the reductions in crop yields would be small or nonexistent. Runoff from corn fields is particularly avoidable because corn's roots penetrate only the top few inches of soil and assimilate nutrients for only two months of the year. In addition, nitrogen losses can be reduced by 30 percent or more if farmers plant winter cover crops, such as rye or wheat, which can help the soil hold nitrogen. These crops also increase carbon sequestration in soils, mitigating climate change. Better yet is to grow perennial plants such as grasses rather than corn; nitrogen losses are many times lower.

Nitrogen pollution from concentrated animal feeding operations

(CAFOs) is a huge problem. As recently as the 1970s, most animals were fed local crops, and the animals' wastes were returned to the fields as fertilizer. Today most U.S. animals are fed crops grown hundreds of miles away, making it "uneconomical" to return the manure. The solution? Require CAFO owners to treat their wastes, just as municipalities must do with human wastes. Further, if we ate less meat, less waste would be generated and less synthetic fertilizer would be needed to grow animal feed. Eating meat from animals that are range-fed on perennial grasses would be ideal.

The explosive growth in the production of ethanol as a biofuel is greatly aggravating nitrogen pollution. Several studies have suggested that if mandated U.S. ethanol targets are met, the amount of nitrogen flowing down the Mississippi River and fueling the Gulf of Mexico dead zone may increase by 30 to 40 percent. The best alternative would be to forgo the production of ethanol from corn. If the country wants to rely on biofuels, it should instead grow grasses and trees and burn these to co-generate heat and electricity; nitrogen pollution and greenhouse gas emissions would be much lower.

THREATS

in bounds



● PHOSPHORUS CYCLE

David A. Vaccari, *director of civil, environmental and ocean engineering, Stevens Institute of Technology*

Phosphorus demand is increasing faster than population because of rising living standards. At current rates, the readily accessible reserves will last less than a century. Thus, our two objectives are to conserve phosphorus as a resource as well as reduce its runoff, which damages coastal ecosystems.

The most sustainable flow of phosphorus through the environment would be the natural flux: seven million metric tons per year (Mt/yr). To hit that mark yet satisfy our usage of 22 Mt/yr, we would have to recycle or reuse 72 percent of our phosphorus, and if demand rose further, even more recycling would have to be done.

The flow could be reduced with existing technologies. Conservation agriculture techniques, such as no-till farming and terracing, could reduce the flow entering rivers by 7.2 Mt/yr. Most farm animal phosphorus waste that is not recycled—about 5.5 Mt/yr finds its way to the sea—could essentially be eliminated by transporting it to agricultural areas where it could be used. For human waste, technologies can increase recovery from 50 to about 85 percent, saving 1.05 Mt/yr.

These actions are the “low-hanging fruit,” based on what is doable rather than what is needed to avoid dangerous scenarios. Yet they would lower the loss to waterways from 22 to 8.25 Mt/yr, not very much above the natural flux.

● CLIMATE CHANGE

Adele C. Morris, *policy director, Climate and Energy Economics Project, Brookings Institution*

Choosing an atmospheric concentration at which to stabilize greenhouse gases, though seemingly a scientific decision, requires weighing the benefits and costs of achieving different targets and determining who will pay. Given how hard that is, we should adopt policies that minimize costs and preserve the consensus for action for many years.

The first step is to not kill consensus in the cradle with short-term ambition, because angry voters will demand defeat of a program they view as excessively costly.

Price-based climate policies can avoid such economic and political thresholds. Domestically, one option is a rising but reasonable economy-wide greenhouse gas tax. Another option is a cap-and-trade system in which emissions permits trade at prices within a preset range that rises over time. A regulated price range would keep the cost of emissions high enough to prompt ambitious reductions but would limit the risk to the economy (and the program itself) if the cap turned out to be inadvertently stringent.

International agreements should also allow price-based commitments as an alternative to strict emissions limits that might prove infeasible. A climate treaty could allow countries to commit to a tax of an agreed level. This flexibility could allay concerns in developing countries that caps could stifle poverty alleviation. Staying within a “safe operating space” will require staying within all the relevant boundaries, including the electorate’s willingness to pay.

● LAND USE

Eric F. Lambin, *professor of earth systems, Stanford University and University of Louvain*

To control the impact of land use, we should focus on the distribution of cropland globally. Intensive agriculture should be concentrated on land that has the best potential for high-yield crops. But a significant fraction of this prime land is being lost. We risk reaching a point where any increase in food (not to mention biofuel) production would prompt rapid clearing of tropical forests and other ecosystems, as well as cropland expansion onto marginal tracts that have lower yields.

We can avoid losing the best agricultural land by controlling land degradation, freshwater depletion and urban sprawl. This step will require zoning and the adoption of more efficient agricultural practices, especially in developing countries. The need for farmland can be

lessened, too, by decreasing waste along the food distribution chain, encouraging slower population growth, ensuring more equitable food distribution worldwide and significantly reducing meat consumption in rich countries.

More land for nature can also be spared by enacting strong set-aside policies, as the European Union has done. A few developing countries (China, Vietnam, Costa Rica) have managed to shift from deforestation to reforestation thanks to better environmental governance, a strong political will to modernize land use, cultural changes and policies that rely on land-use regulations, and incentives to maintain ecosystem services. The challenge for these nations is to continue such policies without having to import more food.



CROPS AND SPRAWL

● OCEAN ACIDIFICATION

Scott C. Doney, senior scientist, Woods Hole Oceanographic Institution

The oceans are becoming more acidic because of worldwide carbon dioxide emissions, yet global, regional and local solutions are possible. Globally, we need to stop putting CO₂ into the atmosphere and to perhaps, eventually, reduce the concentration toward preindustrial levels. The main tactics are raising energy efficiency, switching to renewable and nuclear power, protecting forests and exploring carbon sequestration technologies.

Regionally, nutrient runoff to coastal waters not only creates dead zones but also amplifies acidification. The excess nutrients cause more phytoplankton to grow, and as they die the added CO₂ from their decay acidifies the water. We have to be smarter about how we fertilize fields and lawns and treat livestock manure and sewage. Another measure is to lessen acid rain, caused mostly by power plant and industry emissions; the rain does not stop when it reaches the coastline.

Locally, acidic water could be buffered with limestone or chemical bases produced electrochemically from seawater and rocks. More practical may be protecting specific shellfish beds and aquaculture fisheries. Larval mollusks such as clams and oysters appear to be more susceptible to acidification than adults, and recycling old clamshells into the mud may help buffer pH and provide better substrate for larval attachment. Shellfish hatcheries can control water chemistry and switch to more robust species.

The drop in ocean pH is expected to accelerate in coming decades, so marine ecosystems will have to adapt. We can enhance their chances for success by reducing other insults such as water pollution and overfishing, making them better able to withstand some acidification while we transition away from a fossil-fuel economy.

● FRESHWATER USE

Peter H. Gleick, president, Pacific Institute



Few rational observers deny the need for boundaries to freshwater use. More controversial is defining where those limits are or what steps to take to constrain ourselves within them.

Another way to describe these boundaries is the concept of peak water. Three different ideas are useful. "Peak renewable" water limits are the total renewable flows in a watershed. Many of the world's major rivers are already approaching this threshold—when evaporation and consumption surpass natural replenishment from precipitation and other sources. "Peak nonrenewable" limits apply where human use of water far exceeds natural recharge rates, such as in fossil groundwater basins of the Great Plains, Libya, India, northern China and parts of California's Central Valley. In these basins, an increase in extraction is followed by a leveling off and then reduction, as the costs and amount of effort needed to acquire the dwindling resource rise—a concept similar to that of peak oil.

"Peak ecological" water is the idea that for any hydrological system, increasing withdrawals eventually reach the point where any additional economic benefit of taking the water is outweighed by the additional ecological destruction that causes. Although it is difficult to quantify this point accurately, we have clearly passed the point of

peak ecological water in many basins around the world where huge damage has occurred, including the Aral Sea, the Everglades, the Sacramento–San Joaquin Valley and many watersheds in China.

The good news is that the potential for savings, without hurting human health or economic productivity, is vast. Improvements in water-use efficiency are possible in every sector. More food can be grown with less water (and less water contamination) by shifting from conventional flood irrigation to drip and precision sprinklers, along with more accurately monitoring and managing soil moisture. Conventional power plants can change from water cooling to dry cooling, and more energy can be generated by sources that use extremely little water, such as photovoltaics and wind. Domestically, millions of people can replace water-inefficient appliances with efficient ones, notably washing machines, toilets and showerheads.

● OZONE DEPLETION

David W. Fahey, physicist, National Oceanic and Atmospheric Administration

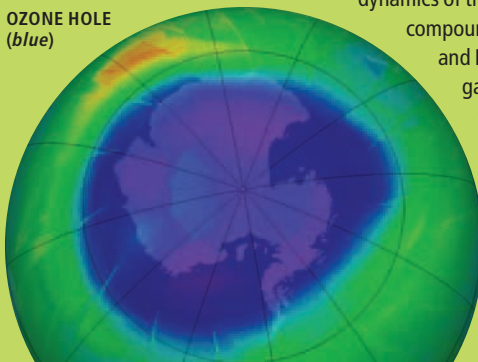
The Montreal Protocol under the Vienna Convention for the Protection of the Ozone Layer has reduced use of ozone-depleting substances—primarily chlorofluorocarbons (CFCs) and halons—by 95 percent over two decades. As of January 1, no more production is to occur in the 195 nations that signed the protocol. As a result, stratospheric ozone depletion will largely reverse by 2100. The gain has relied, in part, on intermediate substitutes, notably hydrochlorofluorocarbons (HCFCs), and the growing use of compounds that cause no depletion, such as hydrofluorocarbons (HFCs).

Ongoing success depends on several steps:

- Continue observing the ozone layer to promptly reveal unexpected changes. Ensure that nations adhere to regulations; for example, the HCFC phaseout will not be complete until 2030.
- Maintain the Scientific Assessment Panel under the protocol. It attributes causes of changes in the ozone layer and evaluates new chemicals for their potential to destroy ozone and contribute to climate change.
- Maintain the Technology and Economic Assessment Panel. It provides information on technologies and substitute compounds that helps nations assess how the demand for applications such as refrigeration, air-conditioning and foam insulation can be met while protecting the ozone layer.

The two panels will also have to evaluate climate change and ozone recovery together. Climate change affects ozone abundance by altering the chemical composition and dynamics of the stratosphere, and compounds such as HCFCs and HFCs are greenhouse gases. For example, the large projected demand for HFCs could significantly contribute to climate change.

● OZONE HOLE (blue)



BREAKING THE GROWTH HABIT

EDITOR'S INTRODUCTION: Scientists have proposed compelling steps to ease specific kinds of environmental damage and slow consumption of certain resources [see "Solutions to Environmental Threats," on page 58]. But Bill McKibben, scholar in residence at Middlebury College and co-founder of climate action group 350.org, maintains that to truly stop ruining the planet, society must break its most debilitating habit: growth.

In his new book, *Eaarth: Making a Life on a Tough New Planet*, McKibben argues that humankind, because of its actions, now lives on a fundamentally different world, which he calls "Eaarth." This celestial body can no longer support the economic growth model that has driven society for 200 years. To avoid our own collapse, we must instead seek to maintain wealth and resources, in large part by shifting to more durable, localized economies.

In the following text, excerpted from parts of the book, McKibben makes his case. And in the sidebars, also condensed from the book, he provides examples of successful local farming and energy production operations.

Society can safeguard its future only by switching from reckless economic growth to smart maintenance of wealth and resources

BY BILL MCKIBBEN

New planets require new habits. If you walk out of the airlock on your Martian base and start breathing, you'll be sorry. We simply can't live on the new earth as if it were the old earth—we've foreclosed that option.

In the world we grew up in, our most ingrained economic and political habit was growth. For the 250 years since Adam Smith, we've assumed that more is better and that the answer to any problem is another burst of expansion. That's because it's worked, at least for a long while: the lives of comfort and

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We can build durable, graceful ways to inhabit this new planet, but first we need to dampen our sense that the future will resemble the past.

relative security that we Westerners lead are the product of 10 generations of steady growth in our economies. But now that we're stuck between a played-out rock and a hot place, it's time to think with special clarity about the future. On our new planet, growth may be the one big habit we finally must break.

* * *

I understand that right now is the worst possible moment to make this point. The temporary halt to growth that we call a recession has—in an economy geared only for expansion—wrecked many lives. We're deep in debt, as individuals and as nations, and in an effort to climb out from underneath that economic burden we've bet yet more money that we can get growth rolling once more. That's what an "economic stimulus" is—a wager that we can restart the growth machine and make back not just the amount we spent stimulating, but the debt that caused the trouble in the first place.

Far worse, of course, is the ecological debt we face—the carbon accumulating in the atmosphere and reshaping the planet. And there, too, the most obvious way out is a new round of growth—a giant burst of economic activity designed to replace our fossil-fuel system with something else that will let us go on living just as we do now (or, better!), but without the carbon. We've seized on the idea of green growth as the path out of all our troubles.

For the record, I support a green Manhattan Project, an ecological New Deal, a cleantech Apollo mission. If I had money, I'd give it to Al Gore to invest in start-ups. These are the obvious and legitimate responses of serious people to the most dangerous crisis we've ever encountered, and to a real degree they're working. We really do need to cut carbon emissions

by 30 percent by 2020, or produce all our electricity from renewable sources within a decade, or meet all the other targets that good people have identified. These actions are precisely the way our system should respond. But it's not going to happen fast enough to ward off enough change to preserve the planet we used to live on. I don't think the growth paradigm can rise to the occasion; I think the system has met its match.

* * *

That perspective may sound a tad grim. But we can build durable and even relatively graceful ways to inhabit this new planet. First, we need to come to terms with where we are. We need to dampen our intuitive sense that the future will resemble the past and our standard-issue optimism that the future will be ever easier. Eearth is an uphill planet now.

I think we know that in our bones. I think we felt it even before the Bush recession settled over us. For Americans, the crucial moment may have come in early 2008, six months before the big banks started tottering, at the moment when the economy still seemed to be roaring but the cost of gasoline spiked to \$4 a gallon.

If the American idea has one constant, it's motion. We arrived here from distant shores, we crossed the continent, we built the highway, we invented the GPS box that sits on your dashboard telling you that you missed your turn. Everything was moving right along. And then, all of a sudden, really for the first time, that motion began to lurch. It began to slow. Each month Americans drove less than the month before. You couldn't sell your old house—but you *really* couldn't sell your old Explorer.

Then something odd started happening. As the price of oil spiked, shipping things long distance started to seem less attractive. By May the cost of sending a shipping container from Shanghai to the U.S. was \$8,000, up from \$3,000 at the beginning of the decade. Cargo volumes began to fall—Ikea opened a plant in Virginia, not China. "The low-hanging fruit of globalization has been picked," a Morgan Stanley currency strategist said. Jeff Rubin, an analyst with CIBC World Markets in Toronto, was blunter: "Globalization is reversible." Indeed, Midwest steelmakers reported a surge in demand, Rubin said, precise-

[THE AUTHOR]



Bill McKibben is a scholar in residence at Middlebury College, a co-founder of the climate action group 350.org and a fellow at the Post Carbon Institute. He is also a former staff writer for the *New Yorker* and has written several notable books about the environment; his latest, *Eearth: Making a Life on a Tough New Planet*, will be released this month.

COURTESY OF NANCIE BATTAGLIA (McKibben)

Local Food Solutions

For the past quarter of a century, despite the rapid spread of massive-scale agribusiness farming, pesticides and genetically engineered crops, the amount of grain per person has been dropping. Serious people have begun to rethink small-scale agriculture, to produce lots of food on relatively small farms with little or nothing in the way of synthetic fertilizer or chemicals.

The new agriculture often works best when it combines fresh knowledge with older wisdom. In Bangladesh a new chicken coop produces not just eggs and meat, but waste that feeds a fishpond, which in turn produces thousands of kilograms of protein annually, and a healthy crop of water hyacinths that are fed to a small herd of cows, whose dung in turn fires a biogas cooking system.

In Malawi, tiny fishponds that recycle waste from the rest of a farm yield on average about 1,500 kilograms of fish. In Madagascar, rice farmers working with European experts have figured out ways to increase yields. They transplant seedlings weeks earlier than is customary, space the plants farther apart, and keep the paddies unflooded during most of the growing season. That means they have to weed more, but it also increases yields fourfold to sixfold. An estimated 20,000 farmers have adopted the full system.

In Craftsbury, Vt., Pete Johnson has helped pioneer year-round farming. Johnson has built solar greenhouses and figured out how to move them on tracks. He now can cover and uncover different fields and grow greens 10 months of the year without any fossil fuels, allowing him to run his community-supported agriculture farm continuously.

I'm not arguing for local food because it tastes better or because it's better for you. I'm arguing that we have no choice. In a world more prone to drought and flood, we need the resilience that comes with three dozen different crops in one field, not a vast ocean of corn or soybeans. In a world where warmth spreads pests more efficiently, we need the resilience of many local varieties and breeds. And in a world with less oil, we need the kind of small, mixed farms that can provide their own fertilizer and build their own soil. —B.M.



PORTABLE GREENHOUSE allows Craftsbury Village Farm to grow vegetables 10 months of the year in chilly Vermont.

ly because “soaring transport costs, first on importing iron to China and then exporting finished steel overseas, have already more than eroded the wage advantage and suddenly rendered Chinese-made steel uncompetitive in the U.S. market.” As the price of oil rose, and with it the demand for ethanol, the cost of food also soared—and suddenly nations began deciding that free trade was not as blindingly obvious as they’d once insisted.

It’s possible that just as we’ve seen the peak of oil, we’ve also seen the peak of economic growth—that we won’t be able to make the system bigger. Insurance costs climb, the price of oil spikes, the economy tanks, the money for new investment in energy evaporates, and when

the economy starts to accelerate again the price of oil spikes. In May 2009 a study from McKinsey & Company called a new oil shock “inevitable.” Rinse, lather, repeat. Except that, because it’s cheap, countries start burning more coal. So, rinse, lather and then stand there with a head full of suds because the rising temperature has evaporated your reservoir.

* * *

Whoever dreamed growth might come to an end? Who indeed. Back in a very different time, when Lyndon Baines Johnson was president, in the spring of Martin Luther King’s assassination and the Broadway opening of *Hair*, a small group of European industrialists and

Local Energy Solutions

It should be clear that fossil fuels define “too big to fail.” In just a few years we’ve got to switch to other energy sources. Local and dispersed works better than centralized, at least in a chaotic world.

Job one, on almost anyone’s list, is conservation. The consulting firm McKinsey & Company estimated in 2008 that existing technologies could cut world energy demand 20 percent by 2020. For supply, it makes financial sense to generate power close to home. Most communities spend 10 percent of their money for fuel, and almost all of it disappears, off to Saudi Arabia or Exxon. Yet in 2008 the Institute for Local Self-Reliance showed that half of all American states could meet their energy needs entirely within their borders, “and the vast majority could meet a significant percentage.” Wind turbines and rooftop solar could provide 81 percent of New York’s power, for instance, and almost one third of Ohio’s.

Local energy is not some romantic notion. In 2009 T. Boone Pickens pulled the plug on the world’s biggest wind farm he’d envisioned for the Texas Panhandle because the transmission lines

were too expensive. He planned instead a series of smaller installations closer to major cities. On the East Coast, plans were still moving ahead for a series of offshore wind farms. The engineers call it “distributed generation,” producing energy where it’s needed instead of ferrying it great distances. More and more companies are installing “micropower” plants to power a building or a campus; they accounted for a third of all new U.S. generation in 2008. In Rizhao, China, a newly emerging metropolitan area of nearly three million, a few local entrepreneurs started putting solar hot-water heaters on each roof in the 1990s. Now virtually all the housing in the city heats water with the sun.

As with our food system, progress would come faster if the government stopped subsidizing the fossil-fuel industry and instead enacted policies such as feed-in tariffs that force utilities to buy the juice from local people at a decent price. That’s what the Germans did, and as a result the nation boasts 1.3 million photovoltaic panels, more than any country on earth.

—B.M.



SOLAR WATER HEATERS are installed on thousands of rooftops in Rizhao, China, reducing electricity demand for domestic hot water.

scientists met in a villa in the Italian capital. Their group—the Club of Rome—proposed to examine interrelated global trends, and they commissioned a report from a team of young systems analysts at the Massachusetts Institute of Technology.

By the time that team had finished its work and issued it as a book called *The Limits to Growth*, in 1972, the first Earth Day had taken place and Richard M. Nixon had created the Environmental Protection Agency. But few events in environmental history were more sig-

nificant than the publication of that slim book, which was translated into 30 languages and sold 30 million copies. The small team of researchers concluded three things:

- “1. If the present growth trends in world population, industrialization, pollution, food production and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next 100 years.
- “2. It is possible to alter these growth trends

and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realize his or her individual human potential.

- “3. If the world’s people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success.”

What’s amazing, in retrospect, is how close we came to listening to their message. Around the world, people got to work figuring out how to slow population growth; educating women turned out to be the best strategy, and so we’ve watched the average mother go from having more than six children to fewer than three in short order. We were paying attention: these were the years of the first oil crises, the first big tanker spills, the first fuel-economy standards for cars. Heck, these were the years when we adopted the 55-mile-per-hour speed limit—when we actually slowed down our mobility in the name of conservation. In the late 1970s more Americans were opposed to continued economic growth than in favor, something that seems almost impossible to us now. We actually had a brief opening to steer a different course, away from the rocks.

We didn’t, of course.

The Club of Rome was not wrong, as it turned out. Just ahead of the curve. You can ignore environmental problems for a long time, but when they catch up to you, they catch up fast. You grow too large, and then you run out of oil and the Arctic melts.

I’ve belabored the point. I’ve belabored it because by now every force in our society is trained to want more growth. But we *can’t* grow. There’s too much friction. We’re on an uphill planet.

* * *

Another possibility exists, however. Like someone lost in the woods, we need to stop running, sit down, see what’s in our pockets that might be of use, and start figuring out what steps to take.

Number one is: mature. We’ve spent 200

Complexity is our vulnerability;
if short-sighted bets on Nevada
mortgages can close thousands of
factories in China, we’ve let our
systems intertwine too much.

years hooked on growth, and it’s done us some good, and it’s done us some bad, but mostly it’s gotten deep inside us, kept us perpetually adolescent. Every politician who ever lived has said: “Our best days are ahead of us.” But they aren’t, not in the way we’re used to reckoning “best.” On a finite planet, that was going to happen someday. It’s just our luck that the music stopped while we were on the floor. So if 2008 turned out to be the year that growth came to an end—or maybe it will be 2011, or 2014, or 2024—well, that’s the breaks. We need to see clearly. No illusions, no fantasies, no melodrama.

Number two: we need to figure out what we must jettison. Many habits, obviously—little things like the consumer lifestyle. But the big item on the list becomes increasingly clear. *Complexity* is the mark of our age, but that complexity rests on the cheap fossil fuel and the stable climate that underwrote huge surpluses of food. Complexity is our glory, but also our vulnerability. As we began to sense with the spike in oil prices and then the credit crunch in 2008, we’ve connected things so tightly that small failures in one place vibrate throughout the entire system. If America’s dumb decision to use a fraction of its corn crop for ethanol can help set off food riots in 37 countries or if a series of short-sighted bets on Nevada mortgages can close thousands of factories in China, then we’ve let our systems intertwine too much. If our bad driving habits can melt the Arctic ice cap—well, you get it.

We’ve turned our sweet planet into Eearth, which is not as nice. We’re moving quickly from a world where we push nature around to a world where nature pushes back—and with far more power. But we’ve still got to live on that world, so we better start figuring out how. ■

➡ MORE TO EXPLORE

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BILL McKIBBEN, CHALLENGED: IS ZERO GROWTH REALLY NECESSARY?

Society always sustained itself locally, until the industrial revolution, when an inexorable march began toward bigger, centralized economies. In *Eaarth: Making a Life on a Tough New Planet*, Bill McKibben says relentless growth is now ruining the globe; maintenance of wealth and resources, instead of expansion, must be society's new driver, or it will perish. Here staff editor Mark Fischetti questions his assertions.

SCIENTIFIC AMERICAN: Your basic message is that humankind must give up growth as its modus operandi. Why can't we just grow more smartly?

McKIBBEN: We can certainly do things more efficiently, and we should. But that's not enough. We are finally hitting the limits to growth that people have talked about since the 1970s, and we are seeing staggering environmental changes. Few people have come to grips with that.

SA: Is absolute, zero growth necessary, or would "very slight" growth be sustainable?

McKIBBEN: I'm not a utopian. I don't have any schema for where the world should come to rest. A specific number is not part of the analysis. I'm more interested in trajectories: what happens if we move away from growth as the answer to everything and head in a different direction. We've been so engrossed in the growth experiment that we've tried very little else. We can measure society by other means. Some countries measure satisfaction. If we measure the world in other ways,

individual accumulation of wealth becomes less important.

SA: The subtext here is that large, centralized, monolithic systems of agriculture, energy and other commerce drive growth. Are you saying big is bad?

McKIBBEN: We built things big because it allowed for faster growth. Efficiencies were gained through size. That's not what we need now. We don't need a racehorse that is exquisitely bred to go as fast as possible but whose ankle breaks the minute there's a divot in the track. We need a plow horse built for durability. Durability needs to be our mantra, instead of expansion.

SA: Is sheer size the culprit, or is it the complexity that size brings? You say that not just banks but more basic industries are "too big to fail." Should such institutions be broken up or disentangled somehow?

McKIBBEN: The financial system, the energy system and the agricultural system share great similarities: a very small number of players, incredibly interwoven. In each case, cascading effects occur when something goes wrong; a chicken pot pie spreads botulism to 48 states. My house runs on solar panels. If it fails, I have a problem, but it doesn't shut down the eastern U.S. power grid.

SA: So you're advocating a return to local reliance. But since E. F. Schumacher's 1973 book, *Small Is Beautiful*, dedicated people have been trying to implement local food and energy systems around the world, yet many regions are still struggling. How small is "local"?

McKIBBEN: We'll figure out the size. It could be a town, a region, a state. But to find the answer, we have to get the incredibly distorting subsidies out of our current systems. They send all kinds of bad signals about what we should be doing. In energy we've underwritten fossil fuel for a long time. It's even more egregious in agriculture. Once subsidies wither, we can figure out what scale of industry makes sense.

SA: Don't local products cost more?

McKIBBEN: We would have more farms, and they might be more labor-intensive, but that



would also create more jobs, and the farmer would reap more of the revenue. Economically, local farms cut out many middlemen. Buying vegetables from CSA [community-supported agriculture] farms is the cheapest way to get food. Meat might still be more expensive, but frankly, eating less meat isn't the end of the world. The best news in my book is the spread, in the past few years, of all kinds of smart, technologically adept, small-scale agricultural techniques around the developing world.

SA: It sounds like the key to local agriculture, at least, is to teach people how to raise yields, without more fertilizer....

MCKIBBEN: Yes, and it depends on where you are. There will not be one system that spreads across the entire world, the way we've tried to spread industrial, synthetic fertilizer-based agriculture. The solutions are much smarter than that. Instead of spreading chemicals, which causes all kinds of problems, we are figuring out alternative methods and how to spread them.

SA: Okay, even if local agriculture works, how does that support durability instead of growth?

MCKIBBEN: Probably the most important assets we can have for long-term stability, especially in an era of ecological upheaval, are good soils—soils that allow you to grow a good amount of food, that can absorb a lot of water because rainfalls are steadily increasing, soils that hold that rainfall through the kinds of extended droughts that are becoming more common. Good soil is precisely what low-impact, low-input, local agriculture builds, and precisely what industrial agriculture destroys.

SA: Local reliance sounds attractive, but how do countries like the U.S. get out of huge debt without growing? The U.S. Treasury Department says the only painless solution is growth. Do we need a transition period where growth eliminates debt, and then we embrace durability?

MCKIBBEN: Well, "painless" is just delay. You know: "Pay me now, or pay me later." The primary political question is: Can we make change happen fast enough to avoid all-out collapses that are plausible, even likely? How do we move these transitions more quickly than they want to move?



SA: What is the most important action to take first?

MCKIBBEN: Change the price of energy to reflect the damage it does to the environment. If fossil fuel reflected that cost, we'd see these new systems and transitions happening much more rapidly. A cap on carbon that raises its price is sine qua non for getting anything done.

SA: A price on carbon is a tough sell....

MCKIBBEN: There's no easy way out of the trouble we're in. But the world we're capable of creating has redeeming qualities, including a much stronger sense of community and a closer connection to other people ... as well as to the natural world. We have assiduously traded community for consumption for a long time. Since the end of World War II, the U.S. has focused on building bigger houses that are farther apart. That has destroyed community. The average American has half as many close friends as individuals had 50 years ago. It's no wonder that by every measure, we are less happy with our lives, even though our material standard of living has trebled. That insight makes it possible to imagine the kind of change we need. Giving up growth for durability will not be all loss. There will be some loss, and there will be some gain.

BILL MCKIBBEN rallies supporters in New York City's Times Square during the International Day of Climate Action on October 24, 2009, one of 5,200 events in 181 countries that his group, 350.org, organized.



More ...

For more of this interview, go to www.ScientificAmerican.com/mckibbenQA

Regaining BALANCE with Bionic Ears

Electronic implants in the inner ear may one day restore clear vision and equilibrium in some patients who experience disabling unsteadiness

By Charles C. Della Santina

KEY CONCEPTS

- Disorders of the vestibular system of the inner ear can cause vertigo and shaky, blurred vision.
- Three semicircular structures in the inner ear are responsible for measuring head rotation.
- Prostheses that would replace the function of the semicircular canals and thus restore balance are under development.

—The Editors

Ask friends to list the body's senses, and they will usually stop after five: taste, touch, sight, smell and hearing. Most do not even notice their sixth sense—the sensation of how one's head is oriented and moving. But losing this capacity can cause dramatic, disabling vertigo, followed by chronic unsteadiness and blurred vision when the head is in motion. Fortunately, good progress is being made toward the development of bionic ear implants to restore balance in people who suffer from damage to the vestibular labyrinth of the inner ear—the part that provides us with our sixth sense.

The availability of these prostheses cannot come too soon for Richard Gannon, a 57-year-old retired steamfitter, who has homes in Pennsylvania and Florida. Gannon lost much of his sensation of balance seven years ago after suffering an apparent viral illness. “Let me be the first to get a vestibular implant,” he says. “I’ve been waiting for a call for five years. As soon as they can do it, I’ll walk to the hospital if I have to.”

“I moved to a house near the beach when I retired because I love the water. But since I lost my balance, I can’t walk straight, especially on sand,” reports Gannon, a formerly avid swimmer. “Now mothers pull their kids away from me, thinking I’m drunk. Standing in two inches of surf makes me feel like I’m going to fall. I

barely drive now, and never at night, because for every headlight, I see 20.”

Although he feels fairly comfortable during daytime driving, he remarks that the cometlike trails left by road lights as they streak across his eyes at night are “like a laser show. I’d give up my hearing if it would mean getting my balance back.” The recent advances toward bionic ear implants offer hope for Gannon and tens of thousands like him who have sustained damage to the inner ear from certain antibiotics (such as gentamicin) or chemotherapy or from meningitis, Ménière’s disease or other illnesses.

Staying Upright and Steady

Much like cochlear implants, which restore hearing by electrically stimulating parts of the auditory nerve, this new type of bionic ear will provide stability by electrically stimulating the vestibular nerve, which normally conveys signals from the vestibular labyrinth to the brain. The device’s electrical connection to the nerve will bypass the defective vestibular system.

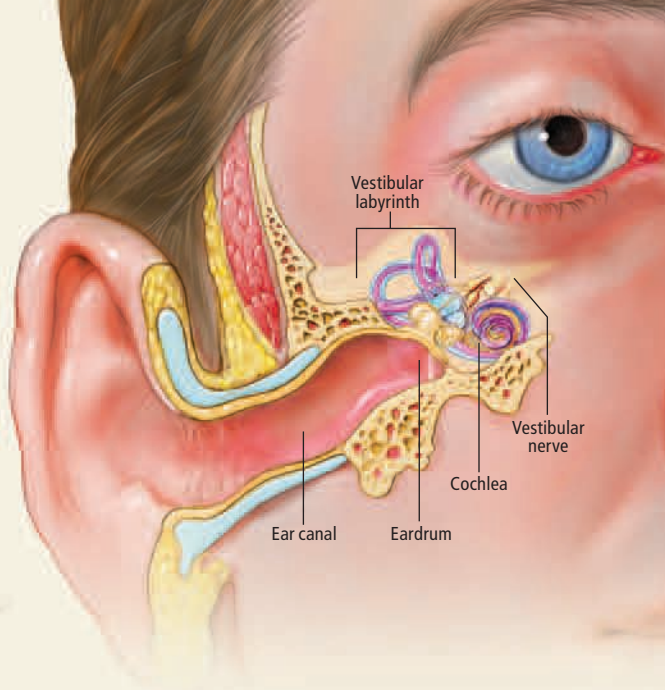
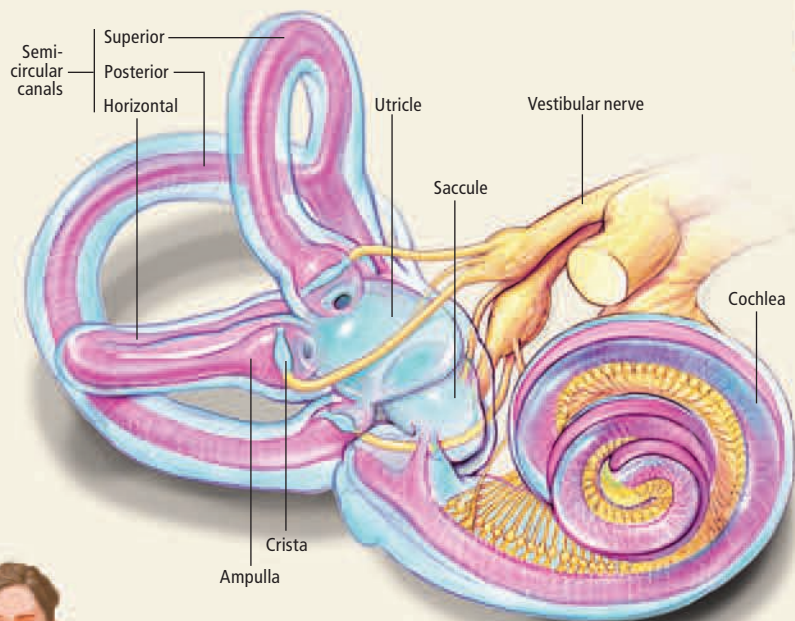
The healthy labyrinth performs two important jobs. One is measuring which way is up and which way you are heading. You need this information to stand and walk normally. The second is sensing how your head is turning. You need this information to keep your eyes on target. Whenever your head turns up, for instance, the



[REPLACEMENT PARTS]

A Device to Restore Balance

The intricately structured vestibular labyrinth of the inner ear is central to balance; damage causes unsteadiness and blurred vision. Researchers are making progress toward a prosthesis that can compensate for such damage, much as implants for hearing loss compensate for harm to the cochlea.

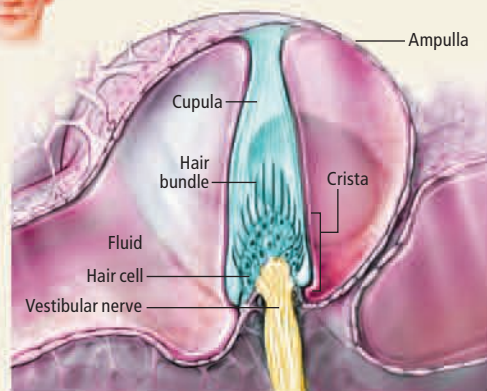


◀ INNER EAR: NOT JUST FOR HEARING

The vestibular labyrinth includes three fluid-filled, Hula-hoop-like structures called semicircular canals, each of which contains a structure termed an ampulla at one end. The ampullae sense head rotation in three dimensions and, like other sensors in the inner ear, rely on specialized cells that translate fluid movement into neural signals. Other structures in the labyrinth—the utricle and saccule—tell the brain how the head is oriented relative to the pull of gravity. The author's prosthesis would replace the function of the semicircular canals.



HEAD STATIONARY



◀ GOING WITH THE FLOW

When the head is stationary, fluid in each semicircular canal remains still and vestibular nerve fibers fire at a constant rate (*top*). During head rotation (*bottom*), fluid in each horizontal semicircular canal bends a cupula (a flexible membrane across the canal). Hair cells translate this motion into electrical signals that are relayed by the fibers to other parts of the brain. These impulses drive reflexes that turn the eyes opposite to the direction of the head's motion, keeping them on target and helping to maintain stable balance.

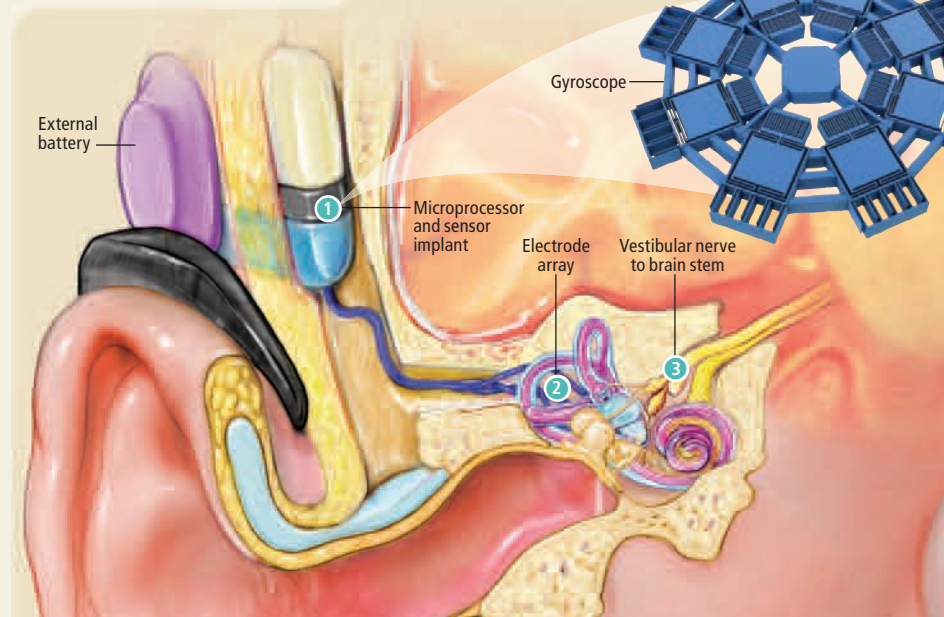


HEAD ROTATING



▼ BALANCE AID: AN ELECTRONIC BYPASS

The planned prosthesis would use a miniature gyroscope to sense head rotation, taking over for defective structures in the ear. The gyroscope sits within a unit implanted behind the ear and consists of a vibrating microelectromechanical wheel (machined using the kind of photolithography that etches computer chips). The wheel deflects slightly when the head moves, changing the voltage on nearby capacitors housed within the hardware ①. A microprocessor in the gyroscope detects this change and sends signals to electrodes inserted in the inner ear ②, which relay the information to the vestibular nerve ③ and thus to the brain stem and, ultimately, to the nerves that adjust the positioning of the eyes.



labyrinth instructs your eyes to rotate down at exactly the same speed, thereby keeping images stable on the retina. Without this vestibulo-ocular reflex, the world would look as if you were watching a movie made by a shaky, handheld video camera. This reflex is the one that would be replaced by the planned prostheses, restoring much but not all of the lost equilibrium.

The vestibular labyrinth measures head rotation using three fluid-filled structures called semicircular canals, so designated because of their Hula-hoop-like shape. The semicircular canals reside in each ear at right angles to one another so that they can register head rotation in three spatial dimensions.

One canal in each ear measures rotation in the horizontal plane, for example. When you turn your head to the left, say, fluid inside the canal exerts pressure on a membrane that stretches across one end of the duct, bending hairlike projections, or cilia, on cells embedded in the base of the structure. The bowing of the cilia triggers signals in vestibular nerves that reach the brain stem and cerebellum, the centers for sensory perception and motor control that send messages to muscles that rotate the eyes opposite to the direction of the head movement.

A Balance Bypass

My colleagues and I at the Johns Hopkins Vestibular Neuroengineering Lab have developed and tested in animals one of the implants of so

much interest to Gannon. It contains a miniaturized (micromechanical) gyroscope that measures head movement in all three dimensions, and its microprocessor sends signals to electrodes that stimulate three branches of the vestibular nerve. Electronics and sensing techniques pioneered for the more than 120,000 cochlear implants during the past 25 years will supply some of the technological underpinnings for this new generation of neural implants, easing the transition from research to clinical use.

We typically implant on only one side, because we would like to limit the surgical risks—such as the possibility of damaging structures in the inner ear involved in hearing—to just one ear. From our animal experiments, we believe a prosthesis that supplants the function of one set of semicircular canals will provide sufficient stability and balance to a patient with a vestibular disorder. Restoring function of structures in the inner ear that serve as gravity sensors might also be possible but should not be necessary to correct the visual blurring that most annoys those who have lost inner ear function.

Beyond the work at Johns Hopkins, other researchers are also developing vestibular implants. Daniel Merfeld, Wangsong Gong and their colleagues at the Massachusetts Eye and Ear Infirmary (MEEI) in Boston reported on the first prosthesis in 2000, a device that served as a replacement for one of the three semicircular canals, and they have shown that animals can adapt to inputs from the implant. Richard Lewis, also at the MEEI, is studying whether that device can stabilize posture.

More recently, a group led by James O. Phillips of the University of Washington has created a pacemakerlike device in an attempt to overcome the abnormal nerve firing that occurs during an attack of vertigo caused by Ménière's disease. Andrei M. Shkel of the University of California, Irvine, and Julius Georgiou of the University of Cyprus are working on integrated circuits to support the effort. Yet another group, led by Conrad Wall of the MEEI, is developing external devices to serve as aids to maintaining stable posture.

Mindful of the disability Gannon and similarly affected patients suffer, our group at Johns Hopkins hopes to begin clinical testing as soon as remaining technical and regulatory hurdles are overcome. If research proceeds as planned, bionic ears that restore the missing sixth sense will finally enable patients like Gannon to regain a sense of balance.

[THE AUTHOR]



Charles C. Della Santina is an associate professor of otolaryngology and biomedical engineering at the Johns Hopkins School of Medicine, where he also directs the Vestibular Neuroengineering Laboratory. His surgical practice focuses on patients with vestibular disorders and on the restoration of hearing by cochlear implants. As a researcher, he concentrates on development of a prosthesis for treatment of individuals disabled by loss of vestibular sensation.

➔ MORE TO EXPLORE

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Johns Hopkins Vestibular Neuroengineering Laboratory:
www.hopkinsmedicine.org/otolaryngology/research/vestibular/VNEL



FIRST VOLUNTEER for a prosthesis is a former steamfitter, Richard Gannon, who became disabled after an illness seven years ago.

ILLUSTRATIONS BY ANDREW SWIFT (opposite page); COURTESY OF RICHARD GANNON (Gannon); COURTESY OF KEITH WELLER, Johns Hopkins Medicine (Della Santina)

TECHNOLOGY

THE RISE OF INSTANT



THE WIRELESS NETWORKS

Wireless networks that do not depend on a fixed infrastructure will allow for ubiquitous connectivity regardless of the situation

By Michelle Effros, Andrea Goldsmith and Muriel Médard

In this era of Facebook, Twitter and the iPhone, it is easy to take for granted our ability to connect to the world. Yet communication is most critical precisely at those times when the communications infrastructure is lost. In Haiti, for example, satellite phones provided by aid agencies were the primary method of communication for days following the tragic earthquake earlier this year. But even ordinary events such as a power outage could cripple the cell phone infrastructure, turning our primary emergency contact devices into glowing paperweights.

In situations such as these, an increasingly attractive option is to create an “ad-hoc” network. Such networks form on their own wherever specially programmed mobile phones or other communications devices are in range of

one another. Each device in the network acts as both transmitter and receiver and, crucially, as a relay point for all the other devices nearby. Devices that are out of range can communicate if those between them are willing to help—passing messages from one to the next like water in a bucket brigade. In other words, each node in the network functions as both a communicator for its own messages and infrastructure for the messages of others.

Disaster relief is but one potential application for ad-hoc networks. They can serve anywhere building a fixed infrastructure would be too slow, difficult or expensive. The military has invested a large amount of money in designing these systems for battlefield communications. Ad-hoc networks in your home would allow devices to find one another and begin communi-

KEY CONCEPTS

- Ad-hoc wireless networks require no fixed infrastructure. Instead they pass information from device to device, forming a web of connections.
- These networks can be used in places where building traditional mobile network infrastructure would prove too unwieldy or expensive—for example, in remote areas and combat zones.
- Because any ad-hoc network is constantly in flux, innovative strategies must be employed to avoid data loss and mitigate interference.



DROPPED CALL: Disasters such as the Haitian earthquake sever communications lines. Ad-hoc networks could be used to connect victims with aid workers and the outside world.

cating automatically, freeing you from the tangle of wires in your living room and office. Remote villages and lower-income neighborhoods that lack a broadband infrastructure could connect via ad-hoc networks to the Internet. Scientists interested in studying microenvironments in the treetops or hydrothermal vents on the ocean floor could scatter sensors in their intended environment without worrying about which sensors will hear one another or how information will travel from the jungle to the researchers' laptops.

These networks have been in development for more than three decades, but only in the past few years have advances in network theory given rise to the first large-scale practical examples. In San Francisco, the start-up Meraki Networks connects 400,000 San Francisco residents to the Internet through their Free the Net project, which relies on ad-hoc networking technology. Bluetooth components in cell phones, computer gaming systems and laptops use ad-hoc networking techniques to enable devices to communicate without wiring or explicit configuration. And ad-hoc networks have been deployed in a variety of remote or inhospitable environments to gather scientific data from low-power wireless sensors. A number of breakthroughs must still be achieved before these networks can become commonplace, but progress is being made on several fronts.

The Cellular Network

Ad-hoc networks are still rare. To understand why they have been slow in coming, it helps to consider the differences between the newer approach and such wireless technologies as cell phones and Wi-Fi. When you use an ordinary mobile phone to call a friend, only the transmissions between each phone and its nearest cell tower are wireless. The towers are fixed in place, and communication between the towers travels through vast networks of wires and cables. Wireless local-area networks such as Wi-Fi also rely on fixed antennas and wireline communications resources.

This approach has advantages and disadvantages. Power is required to transmit information, and classic wireless networks spare the power in battery-powered devices (such as phones and laptops) by leaving as much of the communications burden as possible to a stationary infrastructure that is plugged into the power grid. Similarly, wireless bandwidth is a fixed and limited resource. Traditional wireless systems conserve bandwidth by sending most information through wires. The use of fixed infrastructure allows the construction of large, mostly reliable telephone and Wi-Fi communications resources in areas where the need is greatest.

Yet the use of fixed infrastructure makes these networks vulnerable to power outages and other central failures that can incapacitate a

communications network even if individual phones and laptops in the area can still function. Ad-hoc networks, in contrast, are uniquely robust. If one mobile device runs out of power or is turned off, the remaining ones modify the network to compensate, as much as possible, for the missing constituent. The networks adjust and “heal” naturally as devices come and go.

This self-healing ability comes at a price, though. The network must send information in clever ways so that a message can be reconstructed even if some of the links between sender and receiver break during transit. The system must determine the best way to get a message to the recipient—even if the sending device has no way of knowing where the recipient is. And finally, the network must also deal with the omnipresent noise of multiple devices transmitting messages at similar times.

Delivery Strategies

The problem of how to efficiently route information through an ever changing network has been difficult to resolve for several reasons. In a traditional cell phone or other wireless network, the central wireline infrastructure keeps track of the general locations of individual devices. It

can then take a message from one user and direct that message straight to its recipient.

In contrast, communications devices in ad-hoc networks have to determine on their own the best means of delivering information. The individual instruments are limited in their computing power, memory and communication, so no single individual can gather or process all the information that would be known to the central computers of traditional wireless networks.

The situation can be illustrated through the following scenario: You are in a large city—say, London—and you need to contact your friend who is at some unknown location on the other side of town. In this pretend world, the communications infrastructure is mounted to the roofs of taxicabs. The receiver on each cab has a range of less than a mile, and the taxis travel much more slowly than the speed of communication, so the taxis must work together to deliver your message. As the cabs jostle through the city, nearby receivers connect to each other, then split apart an unpredictable amount of time later. Your call must leapfrog through the city on the back of this undulating network, find your friend, then deliver its information contents.

The task is difficult even for a single message

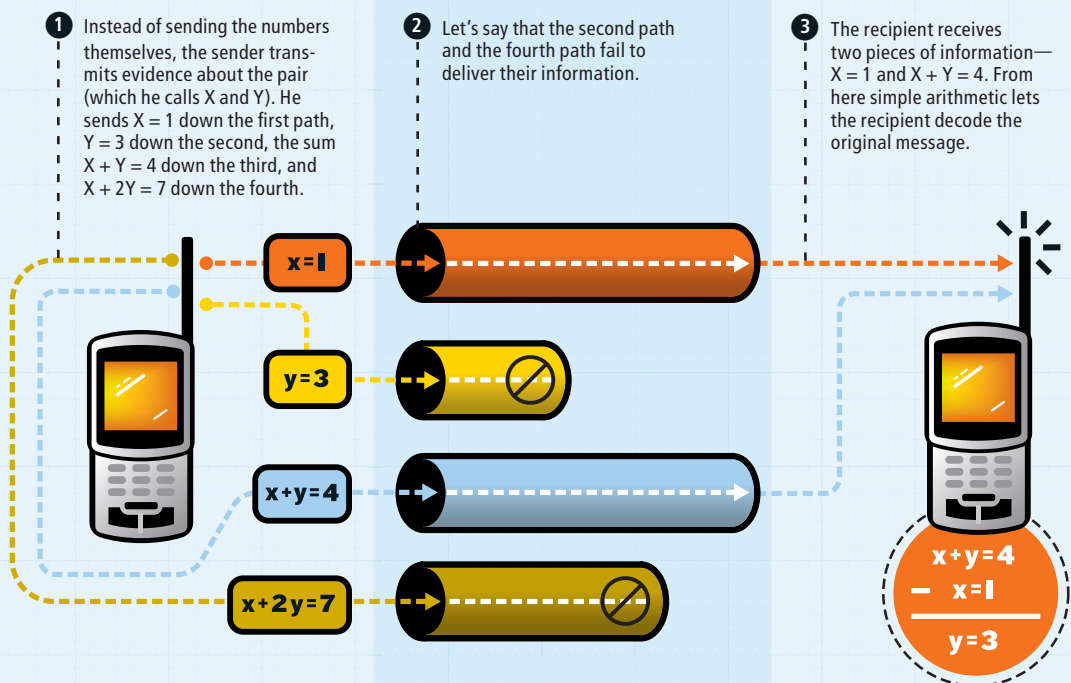
In San Francisco about 400,000 residents access the Internet using ad-hoc networks.



[HOW IT WORKS]

Using Smart Redundancy to Send Messages

In a wireless ad-hoc network, any path carrying information might fail at any time. Thus, the sender must break up the message in some way that allows it to be reconstructed no matter which paths break. In this simple example, the message is the numbers 1 and 3. There are four possible paths, each of which has only a 50–50 chance of working. The naive approach—sending 1 down two paths and 3 down two—could lead to a situation where both 1 paths or both 3 paths fail. Another approach (diagram) guarantees receipt.



[HOW IT WORKS]

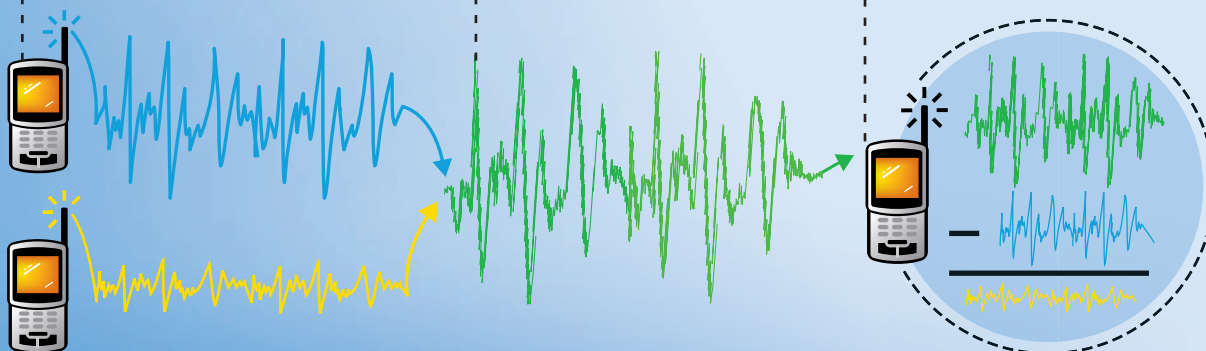
Vary the Volume to Avoid Interference

Wireless ad-hoc networks must deal with severe interference problems—when many devices are transmitting at once, it can be difficult to pluck a single data stream out of the noise. One strategy for overcoming this obstacle is to have devices vary the intensity of their signals. The system works well for two transmissions and one receiver; figuring out how to scale it up is an ongoing research challenge.

1 Two transmitters send information. One is set to transmit "loudly," the other "softly."

2 The combined signal closely resembles the loud transmission.

3 The receiver can discern what the loud transmitter was broadcasting, then subtract this signal out of the combined signal to recover the soft transmission.



moving through a small network; the difficulty only increases as the number of devices and messages grows. For the technology to be really useful, it needs to work efficiently no matter how large or small the network becomes.

Many techniques have been developed to tackle this problem. At their core, they involve a lot of asking directions. One receiver queries its neighbors to see what devices are nearby; those receivers query their neighboring devices, and so on until your friend receives the message. Your friend's reply can travel back along the same path, or the reply can seek out a different path. In this way, each intermediate device creates a list of available paths between you and your friend. These lists allow for a message to reach your friend even if your particular device isn't aware of your friend's location. Because the network is in motion, devices must constantly iterate the process of query and response to keep the menu of available paths up-to-date.

It is also useful to send information along several paths at once, thereby increasing the chance that the message gets through. The question is how redundant the system should be. At one extreme, the network can send the entire message down every path. This strategy increases the chances that the message will get through,

but taking this approach with every message will quickly swamp the network. At the other extreme, we can break up the information into a stream of component chunks, then send each chunk down its own path. This method uses less of the network's resources, but many of the bits may get lost in transit, leaving the recipient with just a partial message.

A technique called network coding offers a middle ground. It involves breaking a message into chunks, coming up with information about those chunks, and then sending that meta information down multiple pathways in such a way that the original message can be reconstructed at the recipient's end even if some of the chunks are lost [see box on preceding page].

One aspect of network coding involves deciding how many paths to send a message through. Increasing the number of paths decreases the impact of any single path failure, although it increases the number of devices involved in a single call. This strategy spreads the load of the call across more participants, decreasing the power burden for each while increasing the amount of coordination required.

As more devices begin transmitting—whether in support of one or many conversations—the chance of interference also increases. Just as it

[THE AUTHORS]

Michelle Effros, Andrea Goldsmith and Muriel Médard are longtime friends and collaborators. Effros is a professor of electrical engineering at the California Institute of Technology. Goldsmith is a professor of electrical engineering at Stanford University and co-founder of Quantenna Communications, which develops wireless networking technology. Médard is on the faculty of the Massachusetts Institute of Technology in the electrical engineering and computer science department.

is difficult to understand anything when too many people speak at once, it is difficult for a wireless device to recover transmitted information when other transmissions occur nearby. These problems are especially troublesome in wireless ad-hoc networks because there is no central controller working to coordinate among the participants.

Interference in wireless networks can be handled in one of two ways. The first is to avoid conflict. If transmissions are rare, the chance that messages will interfere with one another is small. For this strategy, each device breaks information into small pieces and transmits only in short bursts. Because uncoordinated neighbors are unlikely to transmit at the same time, this approach creates less interference than would result if users transmitted information in a slow, steady stream. (The most common wireless networking standard for personal computers relies on this burst approach.)

The second strategy allows two transmitters to send information to a receiver simultaneously but requires one to transmit more quietly than the other. If you speak loudly while someone else whispers, I can typically recover your message without difficulty [see box on opposite page]. If I have a recording, I can then subtract out your message to recover the quieter one.

The second approach turns out to be superior for a network with just two transmitters sending messages and a third receiving them; it becomes much more problematic as the number of speakers grows. The system must somehow coordinate who should transmit at high volume and who should transmit quietly. Coordination itself requires communication; the more effort you spend on coordination, the less bandwidth you have for communication. Finding the best possible strategy remains a topic of ongoing research.

New Tools

Although ad-hoc networks are useful in a wide variety of situations, it can be difficult to determine exactly how useful they can be. Even simple questions about the limits of their performance are hard to measure. At what rate can we transmit information across them? How does this rate depend on how many devices there are in the network and the amount of interference that results? What happens when all devices in the network are moving? And what are the trade-offs between the rate at which information is transmitted, the delay associated with

its delivery, and the robustness of the system?

The value of obtaining these kinds of fundamental performance limits on ad-hoc networks is enormous. The information will provide network designers with new techniques that they can incorporate into their designs and help researchers determine where the biggest gains can be had in existing networks. In addition, awareness of these limits can enable network designers to choose among competing priorities such as data rate, delay and probability of loss. For example, phone calls and teleconferences are extremely sensitive to delay. Large delays or inconsistent packet arrival rates can cause breaks or starts and stops in audio and video transmissions that make conversation difficult. Once designers understand the structure of the specific network they are working on, they can program each application to prioritize its needs—a low delay rate for telephone conversations or a low packet loss for sending essential documents.

This kind of understanding is hard to come by in ad-hoc networks because they are constantly changing. To understand the ultimate limit of the network, you can't just measure how the network is performing now—you have to measure how the network would perform in every possible configuration.

We have taken a new approach to this problem that maps wireless ad-hoc networks onto something we understand much more clearly—ordinary wired networks. Information scientists have in our toolbox more than six decades' worth of methods to study the flow of information in wired networks. These networks do not suffer from interference problems, and the nodes of the network do not move around. If we want to study a certain wireless network, we first model it as a wireline network that captures some central features of the wireless network's behavior. We can then characterize the complete performance limits of the ad-hoc network using its doppelgänger as a guide.

This process helps us build better networks because we can understand the implications of our design choices. It also allows us to determine where our current approaches are doing well and where there is room for improvement.

Even with these tools, we do not expect ad-hoc networks to replace the existing cellular infrastructure. But in the unique situations where ad-hoc networks are essential, such tools will allow for a full understanding of just how powerful the network can be—exactly when it is needed most. ■

To understand the ultimate limit of the network, you have to measure how it would perform in every possible configuration.



MORE TO EXPLORE

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The Hidden Life of

Truffles

Not just for gourmands, truffles play essential roles in the health of ecosystems

By James M. Trappe and Andrew W. Claridge

KEY CONCEPTS

- The truffles that appear on restaurant menus and on the shelves of luxury food purveyors represent only a small fraction of the world's truffle species.
- Truffles figure importantly in ecosystems, sustaining both plants and animals.
- Recognition of the ecological significance of truffles is aiding efforts to conserve threatened species that depend on them.

—The Editors

It's a cool November day near Bologna, Italy. We are strolling through the woods with truffle hunter Mirko Illice and his little dog, Clinto. Clinto runs back and forth among the oak trees sniffing the ground, pausing, then running again. Suddenly, he stops and begins to dig furiously with both paws. "Ah, he's found an Italian white truffle," Mirko explains. "He uses both paws only when he finds one of those." Mirko gently pulls the excited dog from the spot and pushes through the soil with his fingers. He extracts a yellowish brown lump the size of a golf ball and sniffs it. "*Benissimo*, Clinto," Mirko intones. Though not the finest example of the species, *Tuber magnatum*—which grows only in northern Italy, Serbia and Croatia—Clinto's find will fetch a nice price of about \$50 at the Saturday market.

Throughout history, truffles have appeared on the menu and in folklore. The Pharaoh Khufu served them at his royal table. Bedouins, Kalahari Bushmen and Australian Aborigines have hunted them for countless generations in deserts. The Romans savored them and thought they were produced by thunder.

Modern epicures prize truffles for their earthy aroma and flavor and are willing to pay steep prices at the market—recently more than \$3,000 per kilogram for the Italian white variety. Yet despite humanity's abiding interest in the fungi, much about their biology has remained veiled in mystery. Over the past two decades, however, genetic analyses and field observations have clarified the origins and functions of these organisms, revealing that they play key roles in many ecosystems. These findings are informing strategies for conserving some endangered species that rely on these denizens of the underworld.

A Fungus among Us

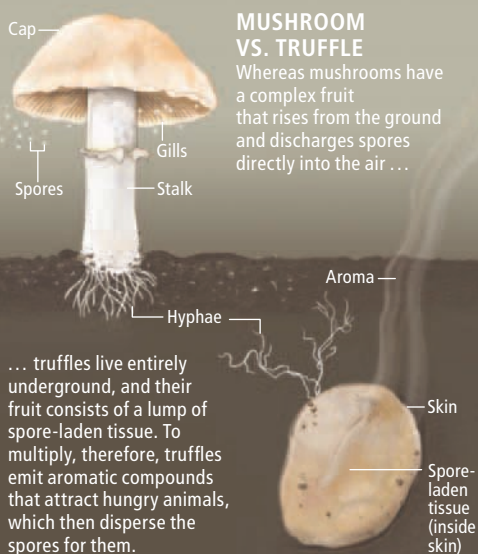
Truffles, like mushrooms, are the fruit of fungi. These fleshy organs are temporary reproductive structures that produce spores, which eventually germinate and give rise to new offspring. What sets truffles apart from mushrooms is that their spore-laden fruit forms below ground rather than above. Technically, true truffles are those fungi that belong to the Ascomycota phylum of organisms and are marketed as food. But there are truffle-like fungi or "false truffles" in the phy-



[ECOLOGICAL SIGNIFICANCE]

Fundamental Fungus

Truffles figure importantly in many ecosystems, benefiting both plants and animals. In the forests of the Pacific Northwest, for example, *Rhizopogon* truffles help Douglas-fir trees to obtain the water and nutrients they need. They also serve as a key source of food for the northern flying squirrel, which in turn is a favorite prey species of the endangered northern spotted owl. Protecting the owl's habitat, then, requires ensuring conditions favorable to truffles.



[THE AUTHORS]

James M. Trappe is scientist emeritus at the U.S. Forest Service and a professor of forest science at Oregon State University. He has discovered more than 200 new truffle species on five continents. Jim wonders why anyone would go fishing instead of seeking new truffles. **Andrew W. Claridge** is a senior research scientist with the New South Wales Department of Environment, Climate Change and Water and a visiting fellow at the University of New South Wales in Australia. He has studied interrelationships among mammals and the fungi they eat for more than 20 years. His favorite hobby is fishing.



lum Basidiomycota that function like true truffles. Given these similarities, we refer to all fleshy fungi that fruit underground as truffles.

Scientific efforts to expose the secrets of truffles date to the 1800s, when German would-be truffle growers asked botanist Albert Bernhard Frank to figure out how the delicacies propagated. Frank's studies revealed that the fungi grow on and into the tiny feeder rootlets that trees use to absorb water and nutrients from the earth. On the basis of those observations, he proposed that the organisms have a symbiotic relationship in which each provides nutrients to the other. He further posited that such relationships between subterranean fungi and plants are widespread and that they shape the growth and health of many plant communities. Frank's theories contradicted conventional wisdom about truffles and other fungi—namely, that they all brought about disease and rot in plants—and drew considerable opposition from his peers. But although nearly a century would pass before scholars had definitive evidence, Frank got the story right.

All truffles and mushrooms produce networks of filaments, or hyphae, that grow between plant rootlets to form a shared absorptive organ known as a mycorrhiza. Thus joined, the fungus provides the plant with precious nutrients and water, its tiny hyphae able to reach into pockets of soil inaccessible to the plant's much larger roots. The plant, in turn, furnishes its consort with sugars and other nutrients that it generates through photosynthesis—products that the fungus needs but cannot produce on its own because it does not photosynthesize. So beneficial is this partnership that nearly all trees and other woody plants require it for survival, as do the associated fungi. Most herbaceous plants (those that do not have a permanent woody stem aboveground) form mycorrhizae too, albeit with different fungi.

Many fungal species, including all the ones that yield truffles, form a variant of the mycorrhiza called an ectomycorrhiza, in which the fungus envelops the feeder rootlets with a protective outer tissue. The diversity of these ectomycor-

rhizal fungi is impressive: one of us (Trappe) estimates that some 2,000 species are associated with the Douglas-fir (an evergreen used for timber and Christmas trees), and probably as many or more types partner only with Australia's eucalyptus trees. Numerous other commercially and ecologically important tree species also rely on ectomycorrhizal fungi. Most of these fungi fruit aboveground as mushrooms, but several thousand species produce truffles.

Going Under

Comparisons of the morphology and gene sequences of truffle and mushroom species indicate that most truffles have evolved from mushrooms. But given that truffles require aboveground dispersal of their spores to propagate, why would natural selection favor the evolution of species that hide underground? Consider the reproductive tactic of mushrooms. Although mushrooms exhibit a multitude of structures and colors, they all have fruiting bodies that can discharge spores directly into the air. The airborne spores may then alight nearby or far away to germinate and potentially establish a new colony in association with the roots of a compatible plant host. It is a highly effective approach.

The mushroom strategy is not foolproof, however. Most mushrooms have little defense against environmental hazards such as heat, drying winds, frost and grazing animals. Every day a few spores mature and are discharged. But if inclement weather dries or freezes a mushroom, spore production usually grinds to a halt.

Where such hazards are commonplace, new evolutionary adaptations have arisen. The most successful alternative has been for the fungus to fruit underground. Once the soil is wet enough for the subterranean fruiting body to form, it is insulated from vagaries of weather. The truffle develops with relative impunity, continuing to produce and nurture its spores even when aboveground conditions become intolerable to mushrooms. At first glance, the truffle's solution might seem facile. The form of a truffle is visibly less complex than that of a mushroom. No longer does the fungus need to expend the energy required to push its spore-bearing tissues aboveground on a stalk or develop a cap or other structure for producing and releasing the spores. The truffle is but a lump of spore-bearing tissue, usually enclosed by a protective skin.

The problem is that the truffles cannot themselves liberate their spores, trapped as they are in their underground realm. That feat demands

an alternative dispersal system. And therein lies the complexity of the truffle's scheme. Over millions of years, as truffles retreated underground, mutations eventually led to the formation of aromatic compounds attractive to animals. Each truffle species has its own array of aromatics that are largely absent in immature specimens but intensify and emerge as the spores mature.

Of the thousands of kinds of truffles that exist today, only a few dozen appeal to humans. The rest are too small or too tough, or they possess aromas that are unremarkable or downright repugnant. To other animals, however, they are irresistible, their olfactory charms wafting up from the soil. Small mammals such as mice, squirrels and rabbits in the Northern Hemisphere and rat-kangaroos, armadillos and meerkats in the Southern Hemisphere are the main truffle gourmands. But their larger counterparts—deer, bears, baboons and wallabies, among others—also seek out the undercover fungi. Mollusks are attracted to truffles, too. And insects may feed on truffles or lay eggs in them so that their larvae have a ready food source when they hatch.

When an animal eats a truffle, most of the flesh is digested, but the spores pass through unharmed and are defecated on the ground, where they can germinate if the conditions are right. This dispersal system has advantages over the one that mushrooms employ. Feces concentrate spores, in contrast to the more diffuse scattering that occurs with aerial dissemination. In addition, feces are more likely to be deposited in the same kinds of areas where the animals forage for truffles, as opposed to the more random transport of airborne spores. This similarity of environment is beneficial because it increases the likelihood that the spores will land in a spot that has an appropriate plant species with which to establish a mycorrhiza.

Not all truffles rely on scent to attract animals, however. In New Zealand, which lacks native terrestrial mammals, some truffles have evolved rainbow hues that mimic the colors of fruits prized by the local birds. The *Paurocotylis pila* truffle, for one, emerges from the ground as it expands and lies on the forest floor, resembling the plump, red berrylike base of the seeds of *Podocarpus* trees that are a favorite bird food. (Although these colorful fungi do poke above the ground, they are nonetheless considered truffles because their spore-bearing tissues are enclosed in a skin, and they thus depend on animals to disperse their spores.)

Yet another dispersal mechanism has evolved

TRUFFLE EATERS

The animals below are among the many that dine on truffles.



Long-footed potaroo



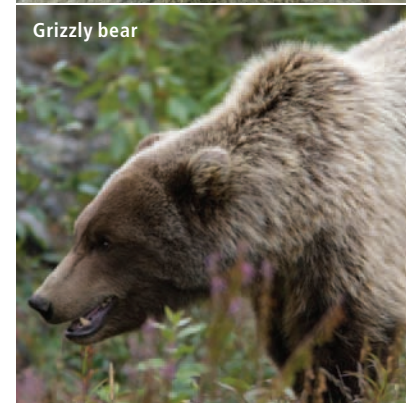
Meerkat



Great spotted kiwi



Chacma baboon

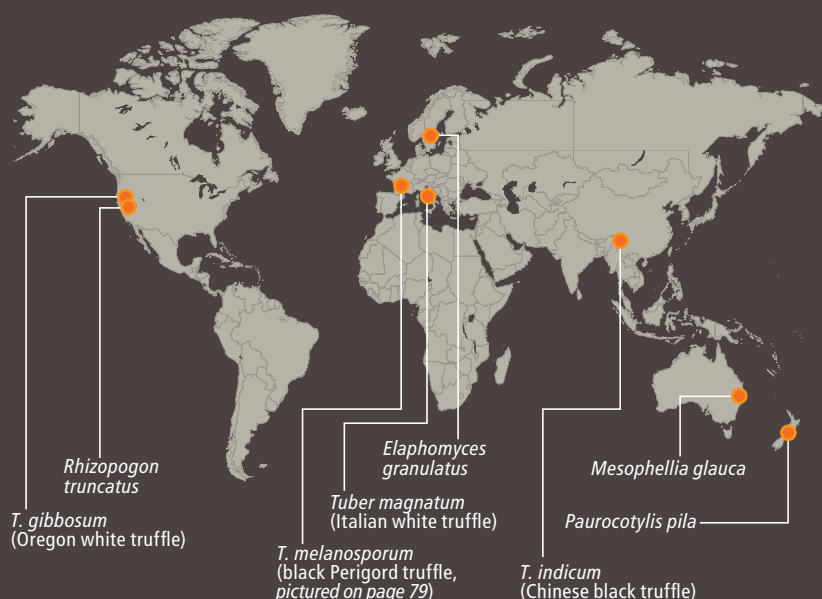


Grizzly bear

[GLOBAL DIVERSITY]

Where Truffles Grow

Truffle species number in the thousands; the map shows representative locations where those mentioned in this article grow wild. The highest-known diversity of species occurs in Mediterranean Europe, western North America and Australia—regions mostly characterized by cool, rainy winters and warm, dry summers. With their subterranean lifestyle, truffles are protected from the heat, drought and frost that can occur when the fungi produce their fruit.



INVADERS AND IMPOSTORS

The black Perigord truffle is under threat from an invader: the Chinese black truffle. Researchers had long been worried that the hearty and adaptable Chinese truffle could spread to the domain of the more finicky Perigord truffle and possibly outcompete it. In 2008 Claude Murat of the University of Torino and his colleagues reported that this fear had been realized: the team detected DNA from both the Perigord truffle and the Chinese truffle in root tips and soil from an Italian truffle plantation.

Dishonest purveyors sometimes try to disguise the much more common Chinese truffle as its rarer and tastier counterpart by mixing small amounts of Perigord truffle in with the Chinese variety to give the latter the right scent. DNA analysis has been used to identify Chinese truffles masquerading as the Perigord kind.

with a few groups of truffles, notably members of the ubiquitous Elaphomycetaceae family and the Mesophelliaceae family, which is endemic to Australasia. Their spores mature into a powder rather than a fleshy, spore-bearing tissue. The powder of *Elaphomyces granulatus*, for instance, is enclosed in a thick rind that is eaten by the animal, freeing the spores. Some of the Mesophelliaceae have a similar structure; others, such as *Mesophellia glauca*, possess a powdery spore mass sandwiched between a thin, hard outer rind and an edible inner core.

Even the spores of uneaten truffles can wander. After maturation, they decay into a slimy, larva-infested suspension in the soil. Invertebrates feed on this rotting tissue or move through it, picking up spores along the way. Truffle spores also travel when predators capture a small truffle-eating species: owls and hawks may carry rodents full of truffles considerable distances to their nests or roosts, where they eat the prey whole or eviscerate and discard the entrails. Either way the spores return to the soil where they may give rise to new truffles.

Together Forever

Evolution's experiments with truffles have been remarkably similar in both the Northern and

Southern Hemispheres, despite taking place long after the continents separated. The host plants in these regions are entirely different: whereas pines, beeches and oaks, for instance, partner with truffles in the north, eucalyptus and southern beeches play that role in the south. The truffle and animal species are likewise distinct between hemispheres. Yet the ecosystems and their components—the trees, truffles and animals—function in much the same way.

The greatest known diversity of truffles occurs in temperate areas of Mediterranean Europe, western North America and Australia (although most of Asia, Africa and South America remain unexplored by truffle researchers). These areas have climates with cool, rainy winters and warm, dry summers. Their fungal fruiting seasons are usually spring and autumn, when weather tends to be erratic: some years bring warm, dry spells and others deliver frost; both conditions are inimical to mushrooms. Over time, then, natural selection favored those fungi that sought refuge underground in these regions.

Exactly when the first truffles evolved is uncertain, but scientists have unearthed some clues to their origins. The oldest fossil ectomycorrhizae on record date to around 50 million years ago. And the ancestors of today's pines and other

LUCY READING-IRKANDA (map); COURTESY OF JAMES M. TRAPPE (*M. glauca*); COURTESY OF MATT TRAPPE (*R. truncatus*); COURTESY OF MICHAEL CASTELLANO AND JAMES M. TRAPPE (*P. pila*)

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trees with which truffles form essential relationships arose some 85 million years ago. We can assume, then, that truffles emerged sometime between 85 million and 50 million years ago.

Given this long-standing association between truffles and plants, it is no surprise that the fungi figure importantly in the ecology of many habitats. Not only are they essential to the functioning of numerous plant species, but animals have come to rely on them for food. In the U.S. at least one creature, the Western red-backed vole, depends almost entirely on truffles for sustenance. And the northern flying squirrel, found in North America, eats mostly truffles when available in the wild. On the other side of the globe, in Australia, a marsupial known as the long-footed potoroo subsists on a diet that is about 95 percent truffles. Its fellow marsupials the other rat-kangaroos and bandicoots also bank heavily on truffles. And many other creatures the world over routinely supplement their primary food sources with these fungi.

Scientists' developing knowledge of the intimate relationship between truffles, their plant hosts and their animal carriers is guiding the efforts of cultivators and conservationists alike. In the 1980s in Oregon, Mike Castellano of the U.S. Forest Service, Mike Amaranthus of Mycorrhizal Applications and their colleagues began outfitting nursery seedlings with spores of hearty *Rhizopogon* truffle species to help the seedlings withstand drought and other stressful conditions in plantations. Going forward, cultivators could conceivably augment their returns if they substituted gourmet truffles for *Rhizopogon*. For example, Christmas tree farms in the Pacific Northwest could additionally produce the delicious Oregon white truffle, *Tuber gibbosum*. Thus far, however, attempts to inoculate trees with this truffle species have produced inconsistent results.

Meanwhile one of us (Claridge) had been using truffles to help determine the population sizes of endangered animals in southeastern Australia—a prerequisite to developing effective protection or recovery programs for these species. He soaks foam pads in olive oil infused with aromatics of the European black Perigord truffle (a favorite of humans) to attract potoroos and other truffle-loving marsupials to stations where they are photographed by motion-sensing digital cameras. This approach has enabled him to detect upward of 50 times as many of these creatures as are counted with the traditional method of cage trapping. If the success rates are this high



FAST FACTS

Black Perigord truffles contain androstenol, a sex hormone found in the saliva of male pigs. The compound is also found in the sweat glands of humans.

Truffle hunters have long used female pigs to locate the fungi underground, but increasingly they are turning to dogs for assistance because the dogs are more willing than the pigs to accept an alternative food reward for their efforts.

Most commercially available truffle oils are flavored synthetically with lab-made compounds such as 2,4-dithiapentane, one of many molecules that give Italian white truffles their distinctive aroma.

Some truffles contain compounds that have potent antituberculosis effects; others exhibit strong anti-inflammatory and antioxidant properties.

➔ MORE TO EXPLORE

Field Guide to North American Truffles: Hunting, Identifying, and Enjoying the World's Most Prized Fungi. Matt Trappe, Frank Evans and James M. Trappe. Ten Speed Press, 2007.

Taming the Truffle: The History, Lore, and Science of the Ultimate Mushroom. Ian R. Hall, Gorton T. Brown and Alessandra Zambonelli. Timber Press, 2007.

Trees, Truffles, and Beasts: How Forests Function. Chris Maser, Andrew W. Claridge and James M. Trappe. Rutgers University Press, 2008.

with imported truffle oil, which he used because it was readily available for purchase, what might the figures be once the odors of native Australian truffles are put to the test? Answering that question is a top priority for his team.

To protect these endangered marsupials and other animals that regularly eat truffles, conservationists will have to ensure the availability of their food. This provision applies not only to those animals that depend directly on truffles but also to their predators. Thus, restoring the habitat of the threatened northern spotted owl in the Pacific Northwest requires meeting the needs of the owl's primary prey, the northern flying squirrel, which eats mostly truffles.

Taming the Truffle

Although researchers have learned much about the ecology of truffles in recent decades, the science of growing them has changed little since the 1960s, when French scientists developed a greenhouse technique for adding spores of the black Perigord truffle into the potting mix of oak and hazel seedlings that are later planted in suitable sites to form truffle orchards, or *truffières*. Under ideal conditions, the *truffières* can produce a crop in four to five years.

After many failed attempts, similar *truffières* were finally established in the U.S. in the 1980s. Today the most productive truffle grower in North America is Tom Michaels of Tennessee Truffles. A former graduate student of Trappe's, Michaels produced an impressive 100 kilograms of Perigord truffles in the 2008–2009 season. To get these results, he pays careful attention to the soil, adding lime every year to keep it friable and well drained. New Zealand and Australia have succeeded in growing Perigord truffles, too.

In stark contrast to the triumphs of Perigord truffle farming, efforts to cultivate the most highly prized truffle species—the Italian white truffle that Mirko and Clinto were hunting, which has an especially intense aroma—have failed. For reasons that remain unknown, this species simply refuses to grow in the greenhouse. To that end, the sequencing of its genome, which is nearing completion, could yield clues to how to coax the king of truffles to grow on command.

Concurrently, truffles may become more prevalent even without cultivation: as the earth warms, the hotter, drier habitats that many truffles favor will spread, setting the stage for increased production and accelerated evolution. Climate change, then, may yield a benefit for some: more truffles for men and beasts. ■

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Imperiled Species ■ Sleeping Sickness ■ Human Ancestors

BY KATE WONG

■ RARE: PORTRAITS OF AMERICA'S ENDANGERED SPECIES

by Joel Sartore. National Geographic Focal Point, 2010 (\$24)

For more than 20 years photojournalist Joel Sartore has been making studio portraits of species from around the world. This book brings together 69 captivating images of organisms on the brink, from the leatherback sea turtle (*right*) to the carnivorous pitcher plant.



ALSO NOTABLE

BOOKS

- **The Lomborg Deception: Setting the Record Straight about Global Warming**
by Howard Friel. Yale University Press, 2010 (\$28)
- **My Brain Made Me Do It: The Rise of Neuroscience and the Threat to Moral Responsibility**
by Eliezer J. Sternberg. Prometheus Books, 2010 (\$21)
- **Cro-Magnon: How the Ice Age Gave Birth to the First Modern Humans**
by Brian Fagan. Bloomsbury Press, 2010 (\$28)
- **Superbug: How MRSA Has Surged Out of Control and Is Lurking in All Corners of Our Lives**
by Maryn McKenna. Free Press, 2010 (\$26)
- **The Battery: How Portable Power Sparked a Technological Revolution**
by Henry Schlesinger. Smithsonian Books, 2010 (\$24.99)
- **Fishes of the Open Ocean: A Natural History and Illustrated Guide**
by Julian Pepperell. University of Chicago Press, 2010 (\$35)
- **In Praise of Science: Curiosity, Understanding, and Progress**
by Sander Bais. MIT Press, 2010 (\$24.95)
- **No Good Deed: A Story of Medicine, Murder Accusations, and the Debate over How We Die**
by Lewis M. Cohen. HarperCollins, 2010 (\$25.99)
- **Arctic Labyrinth: The Quest for the Northwest Passage**
by Glyn Williams. University of California Press, 2010 (\$34.95)



EXCERPT

→ ASLEEP: THE FORGOTTEN EPIDEMIC THAT REMAINS ONE OF MEDICINE'S GREATEST MYSTERIES

by Molly Caldwell Crosby. Berkley Books, 2010 (\$24.95)

Journalist Molly Caldwell Crosby chronicles the chilling history of encephalitis lethargica, or sleeping sickness, that swept across the globe in the shadow of the Spanish Flu, claiming millions of lives before it ended abruptly in 1927. Here she describes the case of a 16-year-old girl named Ruth who lived in New York City and fell fatally ill with the disease in 1918, just as it was building toward an epidemic there.

"... Ruth had been described as a healthy and robust girl, but when she returned from work the week before Christmas, she started complaining of a severe pain in the index finger on her right hand. It was acute and came on suddenly that afternoon.

"By the time she reached home that evening, the pain had spread up her entire arm. The arm ached for hours, and then the pain disappeared suddenly, leaving her right arm slightly paralyzed. Up to that point, an aching arm and what seemed like joint pain had been her only symptoms. The symptoms had come on quickly, but certainly did not point to anything more disturbing to come. And so it was both startling and frightening when Ruth flew into a sudden rage.

"She became irrational and violent, lashing out at her parents. It was as if their daughter had gone insane—immediately and without warning. The family history presented no tendency toward mental illness, and although Ruth's older sister had epilepsy, no epileptic seizure had ever been like this.

"With wild eyes, thrashing limbs and clenched teeth, Ruth finally had to be sedated and restrained. Then Ruth fell asleep. Even as she slept her temperature rose to 102. Her parents could only stand back and watch their daughter, strapped to a bed, gasping in rapid breaths of air like an animal. At first the sleep must have been a relief, but as the days and weeks passed, it would become terrifying.

"Ruth's eyes had closed just before Christmas, and they had never opened again...."



EXHIBITS

- **David H. Koch Hall of Human Origins**, a new permanent exhibit at the National Museum of Natural History in Washington, D.C., opens March 17.



ANCESTRAL HUMANS

- **Lizards and Snakes: Alive!** March 6–September 6, 2010, at the American Museum of Natural History in New York City.

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Wonders of Life

Various items that have come across my desk and did not roll off

BY STEVE MIRSKY



Cheetos Lip Balm. That's right, you can purchase lip balm imbued with the delicate flavor of Cheetos. Somehow I lived in blissful ignorance of that fact until quite recently, when I discovered that chemists had pulled off this minor miracle back in 2005. As I pondered the idea of a cheese-

puffy lip protector, a flood of memories of never having read Proust rose up within me, and I thought of what marvelous recollections he might have come up with had he ever tasted a crunchy curl of faux cheese delicately lifted from a greasy plastic bag, the junkified morsel staining thumb and forefinger a sickly, artificial orange. But I couldn't think about that for long because I was soon busy thinking about other stuff, stuff I'll now ask you, dear reader, to think about, too.

Here's something else I just learned about: in a 2007 poll respondents on average estimated NASA's funding to be 24 percent of the federal budget. Fixing those busted space toilets is expensive, but not that expensive: NASA has in fact been getting about \$18 billion annually in recent years, less than 1 percent of the budget. NASA would get about \$1 billion more each year under the draft budget President Barack Obama announced in early February, although that money would go to scientific research and robotic missions rather than sending guys back to the moon to look for Alan B. Shepard's golf balls. (There are two up there: he shanked his first shot and took the rare moon mulligan.)

Chew on this: animal-rights group PETA says life in captivity is too stressful for groundhogs, which should thus be excused from Groundhog Day festivities. In an interview with blogger Rusty Pritchard, Texas Tech University climatologist Katharine Hayhoe noted that human "climate scientists are often subject to stressful conditions as well, as everything from their sanity to their integrity is attacked on a regular basis."

Here's another idea that's really been vexing me. Human embryonic stem cells are bad, I've been told, because they come from aborted embryos or from surplus embryos created for in vitro fertilization. And using these cells in potentially lifesaving research is morally wrong because even if that embryo was only a few cells or just one cell, it has the potential to be a human being. To some people's

thinking, it already is a human being. On the other completely gestated hand, what are called induced pluripotent stem cells (iPSCs) are allegedly good because no embryos are involved. An iPSC is a tissue-specific adult cell that, with special treatment, has reverted to a fully pluripotent form capable of producing any other kind of cell in the body. In fact, it's theoretically capable of being implanted into a welcoming womb and developing into a human being. Oh, the result would be a clone and therefore pure evil, but it would definitely be a human. So what I don't get is why aren't people who are against using embryonic stem cells in research just as against using iPSCs? Is it because of the evil clone thing?

By the way, freezers in fertility clinics all over the country are filled with those surplus embryos, which some consider to be human beings with all the rights and privileges thereof. And there's a thought experiment in which a fully developed human baby-type person (that detailed description is meant to ward off semantic issues about who's a human or what's a baby) is in the clinic sitting on one of those freezers when a fire breaks out—whom do you save, the crying baby or as many of the frozen embryos as you can? (Hint: if you leave the baby, you don't get invited to the spaghetti dinner at the thought-experiment firehouse.)

Let's move on to this item: the first movie filmed entirely by chimps aired in the U.K. in January, the brainchild of a primatology doctoral candidate who gave cameras to said chimps at the Edinburgh Zoo. Inside sources say that an uncredited William Goldman was brought in to fix script problems and that the Weinsteins plugged gaping holes in the funding after initial filming went way over budget on, here it comes, hair and makeup.

Finally, some really important news. Cola tastes better made with real sugar than with corn syrup. So when I saw a story about Coke now using sugarcane, naturally

I got hyperactive with joy.

Until I found out that the sugarcane isn't going in the soda—it'll be processed to make the bottles. Thus did I cry aspartame tears. True, the new system will use far less petroleum, so it's a good thing. But it could be better if they'd put some sugar water in those sugar bottles. It is, after all, the perfect complement to Cheetos. ■

